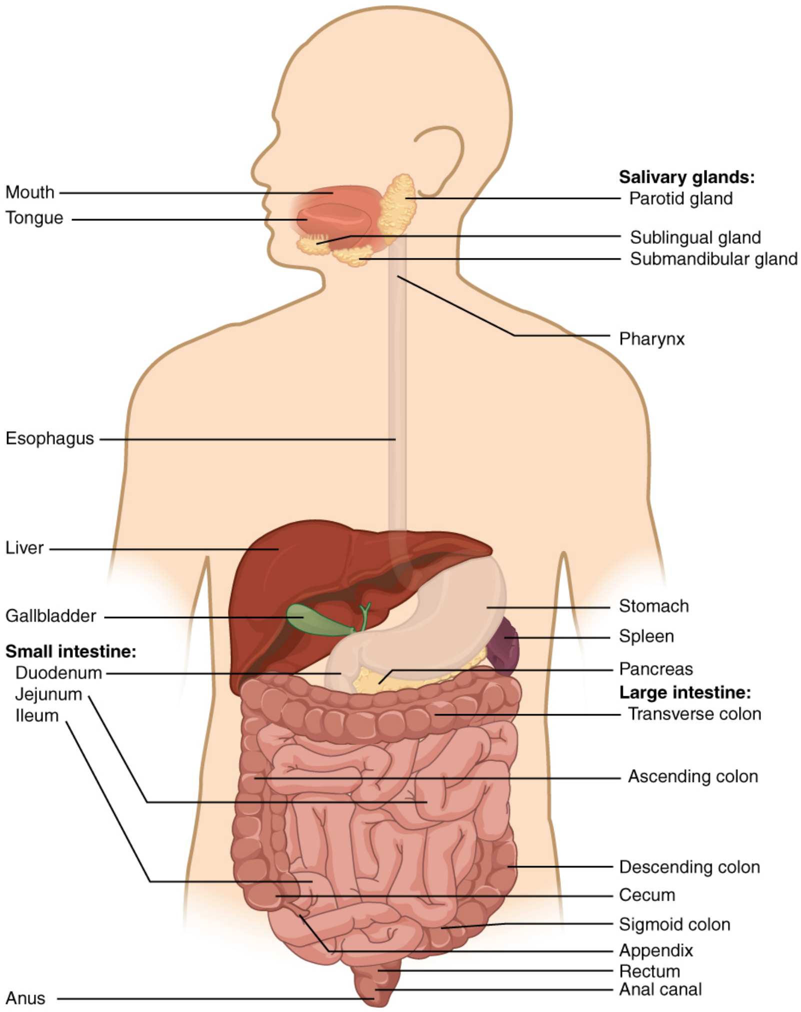
Digestive System Module 1: Overview of the Digestive System
By the end of this section, you will be able to:

- Identify the organs of the alimentary canal from proximal to distal, and briefly state their function
- Identify the accessory digestive organs and briefly state their function
- Describe the four fundamental tissue layers of the alimentary canal
- Contrast the contributions of the enteric and autonomic nervous systems to digestive system functioning
- Explain how the peritoneum anchors the digestive organs

The function of the digestive system is to break down the foods you eat, release their nutrients, and absorb those nutrients into the body. Although **the small intestine is the workhorse of the system, where the majority of digestion occurs**, and where most of the released nutrients are absorbed into the blood or lymph, each of the digestive system organs makes a vital contribution to this process ([link]).

Components of the Digestive System



All digestive organs play integral roles in the life-sustaining process of digestion.

As is the case with all body systems, the digestive system does not work in isolation; it functions cooperatively with the other systems of the body. Consider for example, the interrelationship between the digestive and cardiovascular systems. Arteries supply the digestive organs with oxygen and processed nutrients, and veins drain the digestive tract. These intestinal veins, constituting the hepatic portal system, are unique; they do not return blood directly to the heart. Rather, this blood is diverted to the liver where its nutrients are off-loaded for processing before blood completes its circuit back to the heart. At the same time, the digestive system provides nutrients

to the heart muscle and vascular tissue to support their functioning. The interrelationship of the digestive and endocrine systems is also critical. Hormones secreted by several endocrine glands, as well as endocrine cells of the pancreas, the stomach, and the small intestine, contribute to the control of digestion and nutrient metabolism. In turn, the digestive system provides the nutrients to fuel endocrine function. [link] gives a quick glimpse at how these other systems contribute to the functioning of the digestive system. **You should take notes on this table.**

Contribution of Other Body Systems to the Digestive System	
Body system	**Benefits received by the digestive system**
Cardiovascular	Blood supplies digestive organs with oxygen and processed nutrients
Endocrine	Endocrine hormones help regulate secretion in digestive glands and accessory organs
Integumentary	Skin helps protect digestive organs and synthesizes vitamin D for calcium absorption
Lymphatic	Mucosa-associated lymphoid tissue and other lymphatic tissue defend against entry of pathogens; lacteals absorb lipids; and lymphatic vessels transport lipids to bloodstream
Muscular	Skeletal muscles support and protect abdominal organs

Contribution of Other Body Systems to the Digestive System	
Body system	**Benefits received by the digestive system**
Nervous	Sensory and motor neurons help regulate secretions and muscle contractions in the digestive tract
Respiratory	Respiratory organs provide oxygen and remove carbon dioxide
Skeletal	Bones help protect and support digestive organs
Urinary	Kidneys convert vitamin D into its active form, allowing calcium absorption in the small intestine

Digestive System Organs

The easiest way to understand the digestive system is to divide its organs into two main categories. The first group is the organs that make up the alimentary canal. These organs are part of the "tube" our food travels through from the mouth to the anus. Accessory digestive organs comprise the second group. Food never enters or passes through these organs, but they are critical for orchestrating the breakdown of food. Accessory digestive organs, despite their name, are critical to the function of the digestive system.

Alimentary Canal Organs

Also called the gastrointestinal (GI) tract or gut, the **alimentary canal** (aliment- = "to nourish") is a one-way tube about 25 feet in length The main function of the organs of the alimentary canal is to nourish the body. This tube begins at the mouth and terminates at the anus. Between those two points, the canal is modified as the pharynx (throat), esophagus,

stomach, and small and large intestines to fit the functional needs of the body. Both the mouth and anus are open to the external environment; thus, food and wastes within the alimentary canal are technically considered to be outside the body. Only through the process of absorption do the nutrients in food enter into and nourish the body's "inner space."

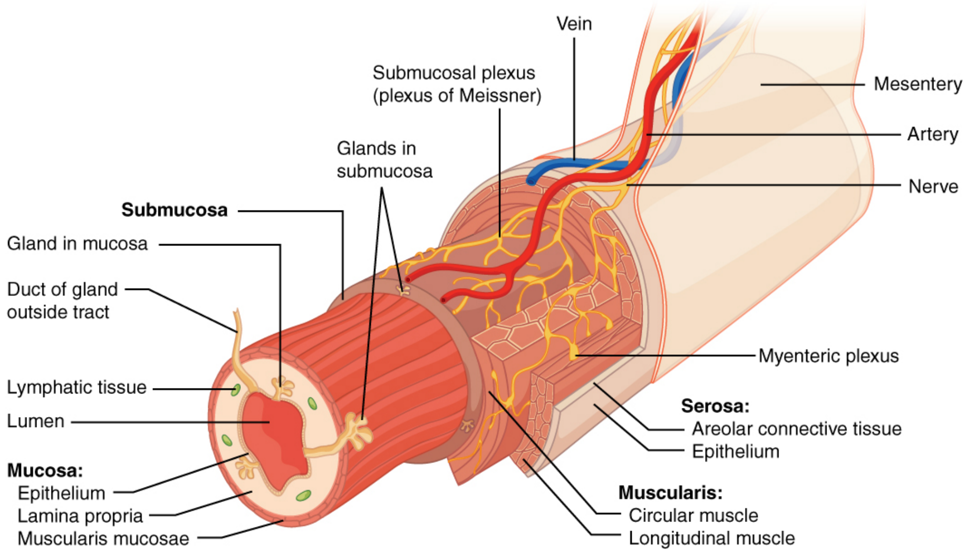
Accessory Structures

Each **accessory digestive organ** aids in the breakdown of food ([link]). The salivary glands, in the mouth, begin the chemical digestion of food. Once food products enter the small intestine, the gallbladder, liver, and pancreas release secretions—such as bile and enzymes—essential for digestion to continue. Together, these are called accessory organs because although they are important, food does not pass through them. You could not live without their vital contributions, and many significant diseases result from their malfunction.

Tissues of the Alimentary Canal

Throughout its length, the alimentary tract is composed of the same four tissue layers; the details of their structural arrangements vary to fit their specific functions. Starting from the lumen and moving outwards, these layers are the mucosa, submucosa, muscularis, and serosa, which is continuous with the mesentery (see [link]).

Layers of the Alimentary Canal



The wall of the alimentary canal has four basic tissue layers: the mucosa, submucosa, muscularis, and serosa.

The **mucosa** is referred to as a mucous membrane, because mucus production is a characteristic feature of this layer. The membrane consists of epithelium, which is in direct contact with ingested food.*Epithelium*—is a type of tissue, found in the mouth, stomach, intestines, pharynx, esophagus,and anal canal, The beginning and end of tube is lined with of a type of epithelium called **stratified squamous epithelium**. The stomach and intestines are lined **simple columnar epithelium**. Notice that the epithelium is in direct contact with the space inside the alimentary canal called the **lumen**.

As its name implies, the **submucosa** lies immediately beneath the mucosa. It is composed of another tissue known as **dense connective tissue**. The **mucosa** is referred to as a mucous membrane, because mucus production is a characteristic feature of this layer. It includes blood and lymphatic vessels (which transport absorbed nutrients).

The third layer of the alimentary canal is the **muscularis**. The muscularis in the small intestine is made up of a double layer of smooth muscle. The

contractions of these layers promote mechanical digestion, expose more of the food to digestive chemicals, and move the food along the canal.

The **serosa** is the outermost layer of the alimentary canal, superficial to the muscularis. Instead of serosa, the mouth, pharynx, and esophagus have a dense sheath of collagen fibers called the adventitia. These tissues serve to hold the alimentary canal in place near the ventral surface of the vertebral column.

Nerve Supply

As soon as food enters the mouth, it is detected by receptors that send impulses along the sensory neurons of cranial nerves. Without these nerves, not only would your food be without taste, but you would also be unable to feel either the food or the structures of your mouth, and you would be unable to avoid biting yourself as you chew, an action enabled by the motor branches of cranial nerves. In addition the **nervous system** controls the **movement of food** through the alimentary tube and **controls the release of enzymes and hormones** that are important in the digestion and absorption of food

Blood Supply

The blood vessels serving the digestive system have two functions. **They transport the protein and carbohydrate nutrients** absorbed by cells after food is digested in the lumen. **Lipids are absorbed via lacteals**, tiny structures of the lymphatic system. The blood vessels' second function is to supply the organs of the alimentary canal with the **nutrients and oxygen** needed to drive their cellular processes.

The veins that collect nutrient-rich blood from the small intestine (where most absorption occurs) empty into the **hepatic portal system**. This network takes the blood into the liver where the nutrients are either processed or stored for later use. Only then does the blood circulate back to the heart.

Chapter Review

The digestive system includes the organs of the alimentary canal and accessory structures. The alimentary canal forms a continuous tube that is open to the outside environment at both ends. The organs of the alimentary canal are the mouth, pharynx, esophagus, stomach, small intestine, and large intestine. The accessory digestive structures include the teeth, tongue, salivary glands, liver, pancreas, and gallbladder. The wall of the alimentary canal is composed of four basic tissue layers: mucosa, submucosa, muscularis, and serosa. The enteric nervous system provides intrinsic innervation, and the autonomic nervous system provides extrinsic innervation.

Glossary

accessory digestive organ
: includes teeth, tongue, salivary glands, gallbladder, liver, and pancreas

alimentary canal
: continuous muscular digestive tube that extends from the mouth to the anus

motility
: movement of food through the GI tract

mucosa
: innermost lining of the alimentary canal

muscularis
: muscle (skeletal or smooth) layer of the alimentary canal wall

myenteric plexus
: (plexus of Auerbach) major nerve supply to alimentary canal wall; controls motility

retroperitoneal
: located posterior to the peritoneum

serosa

outermost layer of the alimentary canal wall present in regions within the abdominal cavity

submucosa

layer of dense connective tissue in the alimentary canal wall that binds the overlying mucosa to the underlying muscularis

submucosal plexus

(plexus of Meissner) nerve supply that regulates activity of glands and smooth muscle

Digestive System Module 2: Processes and Regulation
By the end of this section, you will be able to:

- Discuss six fundamental activities of the digestive system, giving an example of each
- Compare and contrast the neural and hormonal controls involved in digestion

Note: Take notes on the major functions.

Functions of the Digestive Organs		
Organ	**Major functions**	**Other functions**
Mouth	Ingests food Chews and mixes food Begins chemical breakdown of carbohydrates Moves food into the pharynx	Moistens and dissolves food, allowing you to taste it Cleans and lubricates the teeth and oral cavity Has some antimicrobial activity

Functions of the Digestive Organs		
Organ	**Major functions**	**Other functions**
Pharynx	Propels food from the oral cavity to the esophagus	Lubricates food and passageways
Esophagus	Propels food to the stomach	Lubricates food and passageways
Stomach	Mixes and churns food with gastric juices to form chyme Begins chemical breakdown of proteins Releases food into the duodenum as chyme Absorbs some fat-soluble substances (for example, alcohol, aspirin) Possesses antimicrobial functions	Stimulates protein-digesting enzymes Secretes intrinsic factor required for vitamin B_{12} absorption in small intestine

Functions of the Digestive Organs		
Organ	**Major functions**	**Other functions**
Small intestine	Mixes chyme with digestive juices to further break down food Propels food at a rate slow enough for digestion and absorption Absorbs breakdown products of carbohydrates, proteins, lipids, and nucleic acids, along with vitamins, minerals, and water Performs physical digestion via segmentation	Provides optimal medium for enzymatic activity

Functions of the Digestive Organs		
Organ	**Major functions**	**Other functions**
Accessory organs	Liver: produces bile salts, which emulsify lipids, aiding their digestion and absorption Gallbladder: stores, concentrates, and releases bile Pancreas: produces digestive enzymes and bicarbonate	Bicarbonate-rich pancreatic juices help neutralize acidic chyme and provide optimal environment for enzymatic activity
Large intestine	Further breaks down food residues Absorbs most residual water, electrolytes, and vitamins produced by enteric bacteria Propels feces toward rectum Eliminates feces	Food residue is concentrated and temporarily stored prior to defecation Mucus eases passage of feces through colon

Digestive Processes

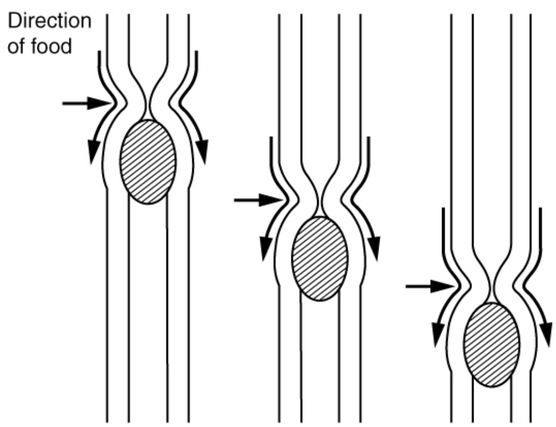
The processes of digestion include six activities: ingestion, propulsion, mechanical or physical digestion, chemical digestion, absorption, and

defecation.

The first of these processes, **ingestion**, refers to the entry of food into the alimentary canal through the mouth. There, the food is chewed and mixed with saliva, which contains enzymes that begin breaking down the carbohydrates in the food. Chewing increases the surface area of the food and allows an appropriately sized **bolus** (ball of chewed food) to be produced.

Food leaves the mouth when the tongue and throat muscles propel it into the esophagus. This act of swallowing, the last voluntary act until defecation, is an example of **propulsion**, which refers to the movement of food through the digestive tract. It includes both the voluntary process of swallowing and the involuntary process of peristalsis. **Peristalsis** consists of sequential, alternating waves of contraction and relaxation of alimentary wall smooth muscles, which act to propel food along ([link]). These waves also play a role in mixing food with digestive juices. Peristalsis is so powerful that foods and liquids you swallow enter your stomach even if you are standing on your head.

Peristalsis



Peristalsis moves food through the digestive tract with alternating waves of muscle contraction and relaxation.

Digestion includes both mechanical and chemical processes. **Mechanical digestion** is a purely physical process that does not change the chemical nature of the food. Instead, it makes the food smaller to increase both surface area and mobility. It includes **mastication**, or chewing, as well as tongue movements that help break food into smaller bits and mix food with saliva. Although there may be a tendency to think that mechanical digestion is limited to the first steps of the digestive process, it occurs after the food leaves the mouth, as well. The mechanical churning of food in the **stomach** serves to further break it apart and expose more of its surface area to digestive juices, creating an acidic "soup" called **chyme**. **Segmentation**, which occurs mainly in the small intestine, consists of localized contractions of circular muscle of the muscularis layer of the alimentary canal. These contractions move their contents back and forth while continuously subdividing, breaking up, and mixing the contents.

In **chemical digestion**, starting in the mouth, digestive secretions break down complex food molecules into their chemical building blocks (for example, proteins into separate amino acids). These secretions vary in composition, but typically contain water, various enzymes, acids, and salts. The process is completed in the small intestine.

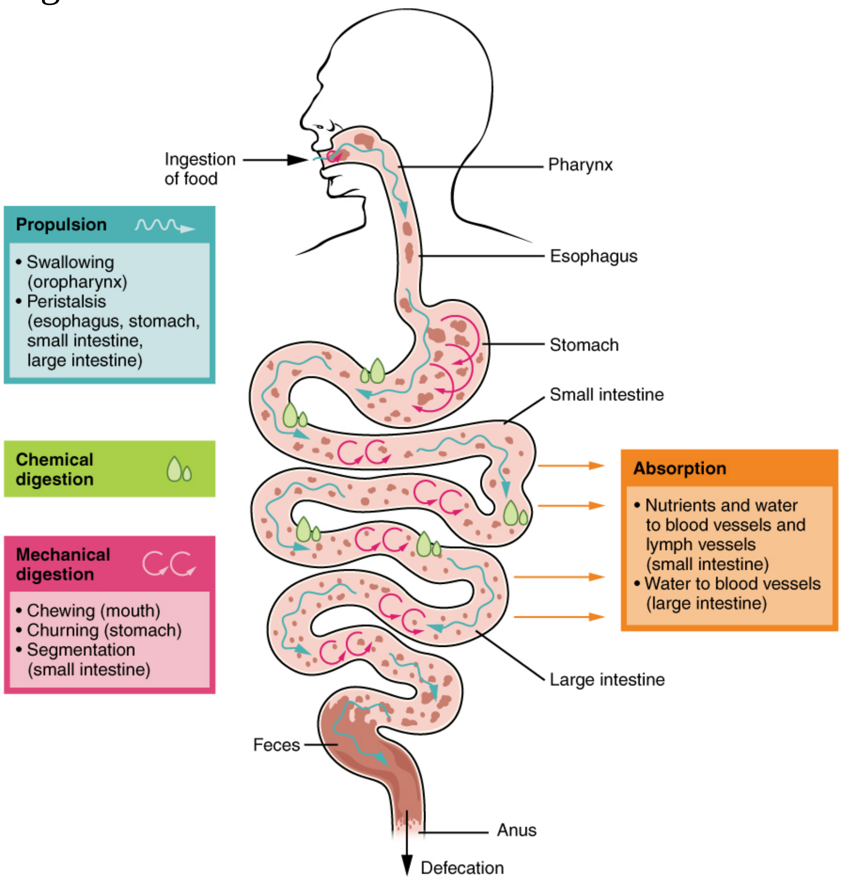
Food that has been broken down is of no value to the body unless it enters the bloodstream and its nutrients are put to work. This occurs through the process of **absorption**, which takes place primarily within the small intestine. There, most nutrients are absorbed **from the lumen of the alimentary canal into the bloodstream** through the epithelial cells that make up the mucosa. Lipids are absorbed into lacteals and are transported via the lymphatic vessels to the bloodstream. Remember that digestion and absorption are **different processes**. The details of these processes will be discussed later.

In **defecation**, the final step in digestion, undigested materials are removed from the body as feces.

In some cases, a single organ is in charge of a digestive process. For example, ingestion occurs only in the mouth and defecation only in the anus. However, most digestive processes involve the interaction of several

organs and occur gradually as food moves through the alimentary canal ([link]).

Digestive Processes



The digestive processes are ingestion, propulsion, mechanical digestion, chemical digestion, absorption, and defecation.

Some chemical digestion occurs in the mouth. Some absorption can occur in the mouth and stomach, for example, alcohol and aspirin.

Regulatory Mechanisms

The nervous and endocrine systems mechanisms work to maintain the optimal conditions in the lumen needed for digestion and absorption. These

regulatory mechanisms, which stimulate digestive activity through mechanical and chemical activity.

Neural Controls

The walls of the alimentary canal contain a variety of **sensors** that help regulate digestive functions. For example, these receptors can sense when the presence of food has caused the stomach to expand, whether food particles have been sufficiently broken down, how much liquid is present, and the type of nutrients in the food (lipids, carbohydrates, and/or proteins). Another example is that the sight, smell, and taste of food initiate long reflexes that begin with a sensory neuron delivering a signal to the brain. The signal stimulates cells in the stomach to begin secreting digestive juices in preparation for incoming food.

Hormonal Controls

A variety of hormones are involved in the digestive process. The main digestive hormone of the stomach is gastrin, which is secreted in response to the presence of food. **Gastrin** stimulates the secretion of gastric acid by the parietal cells of the stomach. Other GI hormones are produced and act upon the gut and its accessory organs. Hormones produced by the duodenum include **secretin**, which stimulates a watery secretion of bicarbonate by the pancreas; **cholecystokinin (CCK)**, which stimulates the secretion of pancreatic enzymes and bile from the liver and release of bile from the gallbladder; and **gastric inhibitory peptide**, which slows gastric secretion and gastic emptying.These GI hormones are secreted by specialized epithelial cells, called **endocrinocytes**, located in the lining of the stomach and small intestine. These hormones then enter the, through the **bloodstream** which they can reach their target organs.

Chapter Review

The digestive system ingests and digests food, absorbs released nutrients, and excretes food components that are indigestible. The six activities involved in this process are ingestion, motility, mechanical digestion, chemical digestion, absorption, and defecation. These processes are regulated by neural and hormonal mechanisms.

Glossary

absorption
: passage of digested products from the intestinal lumen through mucosal cells and into the bloodstream or lacteals

chemical digestion
: enzymatic breakdown of food

chyme
: soupy liquid created when food is mixed with digestive juices

defecation
: elimination of undigested substances from the body in the form of feces

ingestion
: taking food into the GI tract through the mouth

mastication
: chewing

mechanical digestion
: chewing, mixing, and segmentation that prepares food for chemical digestion

peristalsis
: muscular contractions and relaxations that propel food through the GI tract

propulsion

voluntary process of swallowing and the involuntary process of peristalsis that moves food through the digestive tract

segmentation
: alternating contractions and relaxations of non-adjacent segments of the intestine that move food forward and backward, breaking it apart and mixing it with digestive juices

Digestive System Module 3: The Mouth, Pharynx, and Esophagus
By the end of this section, you will be able to:

- Describe the structures of the mouth, including its three accessory digestive organs
- Group the 32 adult teeth according to name, location, and function
- Describe the process of swallowing, including the roles of the tongue, upper esophageal sphincter, and epiglottis
- Trace the pathway food follows from ingestion into the mouth through release into the stomach

In this section, you will examine the anatomy and functions of the three main organs of the upper alimentary canal—the mouth, pharynx, and esophagus—as well as three associated accessory organs—the tongue, salivary glands, and teeth.

The Mouth

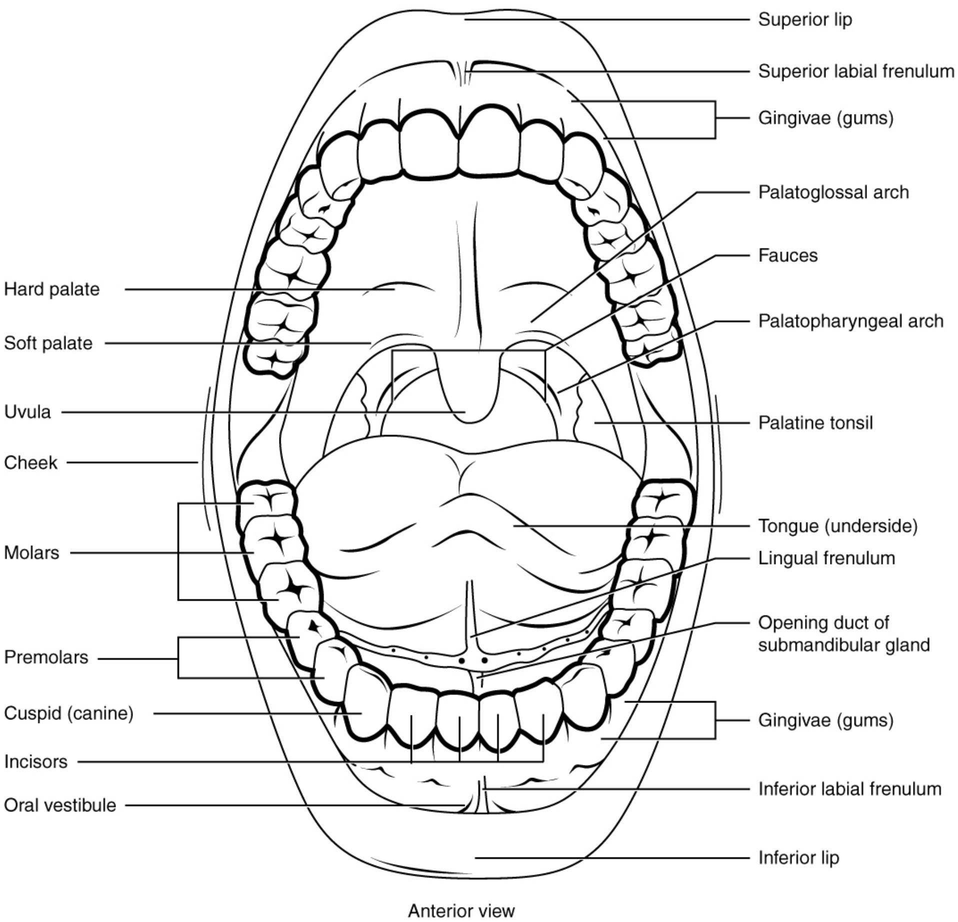
The cheeks, tongue, and palate frame the mouth, which is also called the **oral cavity** (or buccal cavity). The structures of the mouth are illustrated in [link].

At the entrance to the mouth are the lips, or **labia** (singular = labium). The lips cover the **orbicularis oris** muscle, which regulates what comes in and goes out of the mouth. The cheeks make up the oral cavity’s sidewalls. The next time you eat some food, notice how the muscles in your cheeks and the orbicularis oris muscle in your lips contract, helping you keep the food from falling out of your mouth.

When you are chewing, you do not find it difficult to breathe simultaneously. The next time you have food in your mouth, notice how the arched shape of the roof of your mouth allows you to handle both digestion and respiration at the same time. This arch is called the **palate**. The anterior region of the palate serves as a wall (or septum) between the oral and nasal cavities as well as a rigid shelf against which the tongue can push food. It is created by bones of the skull and, given its bony structure, is known as the **hard palate**. If you run your tongue along the roof of your mouth, you’ll

notice that the hard palate ends in the posterior oral cavity, and the tissue becomes fleshier. This part of the palate, known as the **soft palate**, is composed mainly of skeletal muscle. You can therefore manipulate, subconsciously, the soft palate—for instance, to yawn, swallow, or sing (see [link]).

Mouth



The mouth includes the lips, tongue, palate, gums, and teeth.

A fleshy bead of tissue called the **uvula** drops down from the center of the posterior edge of the soft palate. It serves an important purpose. When you swallow, the soft palate and uvula move upward, helping to keep foods and liquid from entering the nasal cavity. Unfortunately, it can also contribute to the sound produced by snoring.

The Tongue

Perhaps you have heard it said that the **tongue** is the strongest muscle in the body. Those who stake this claim cite its strength proportionate to its size. Although it is difficult to quantify the relative strength of different muscles, it remains indisputable that the tongue is a workhorse, facilitating ingestion, mechanical digestion, sensation (of taste, texture, and temperature of food), swallowing, and vocalization. Working in concert, the muscles of the tongue perform three important digestive functions in the mouth: (1) position food for optimal chewing, (2) gather food into a **bolus** (rounded mass), and (3) position food so it can be swallowed.

The Salivary Glands

Many small **salivary glands** are housed within the mouth. These minor exocrine glands are constantly secreting saliva, either directly into the oral cavity or indirectly through ducts, even while you sleep. In fact, an average of 1 to 1.5 liters of saliva is secreted each day. Usually just enough saliva is present to moisten the mouth and teeth. Secretion increases when you eat, because saliva is essential to moisten food and **initiate the chemical breakdown of carbohydrates**.

The Major Salivary Glands

Outside the oral mucosa are three pairs of major salivary glands, which secrete the majority of saliva into ducts that open into the mouth:

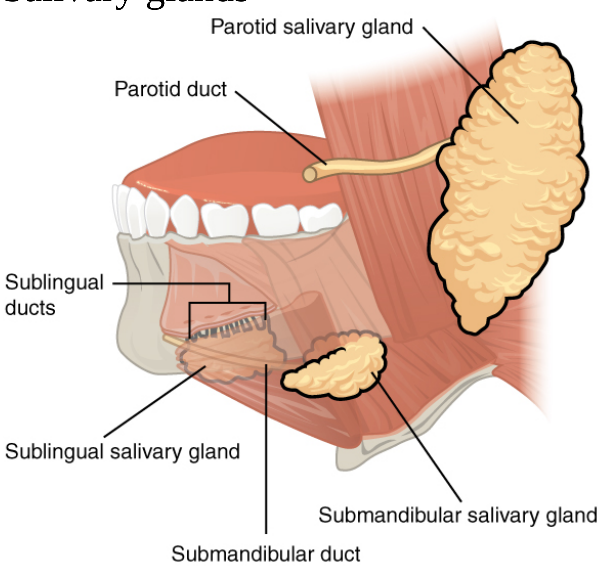
- The **submandibular glands**, which are in the floor of the mouth, secrete saliva into the mouth through the submandibular ducts.
- The **sublingual glands**, which lie below the tongue, use the lesser sublingual ducts to secrete saliva into the oral cavity.
- The **parotid glands** lie between the skin and the masseter muscle, near the ears. They secrete saliva into the mouth through the parotid duct, which is located near the second upper molar tooth ([link]).

Saliva

Saliva is essentially (95.5 percent) water. The remaining 4.5 percent is a complex mixture of ions, glycoproteins, enzymes, growth factors, and waste products. Perhaps the most important ingredient in saliva from the perspective of digestion is the enzyme **salivary amylase**, which initiates the breakdown of carbohydrates. Food does not spend enough time in the mouth to allow all the carbohydrates to break down, but salivary amylase continues acting until it is inactivated by stomach acids. Salivary mucus helps lubricate food, facilitating movement in the mouth, bolus formation, and swallowing.

Each of the major salivary glands secretes a unique formulation of saliva according to its cellular makeup. For example, the **parotid glands** secrete a watery solution that contains salivary amylase. The **submandibular glands** have cells similar to those of the parotid glands, as well as mucus-secreting cells. Therefore, saliva secreted by the submandibular glands also contains amylase but in a liquid thickened with mucus. The **sublingual glands** contain mostly mucous cells, and they secrete the thickest saliva with the least amount of salivary amylase.

Salivary glands



The major salivary glands are located outside the oral mucosa

and deliver saliva into the
mouth through ducts.

The Teeth

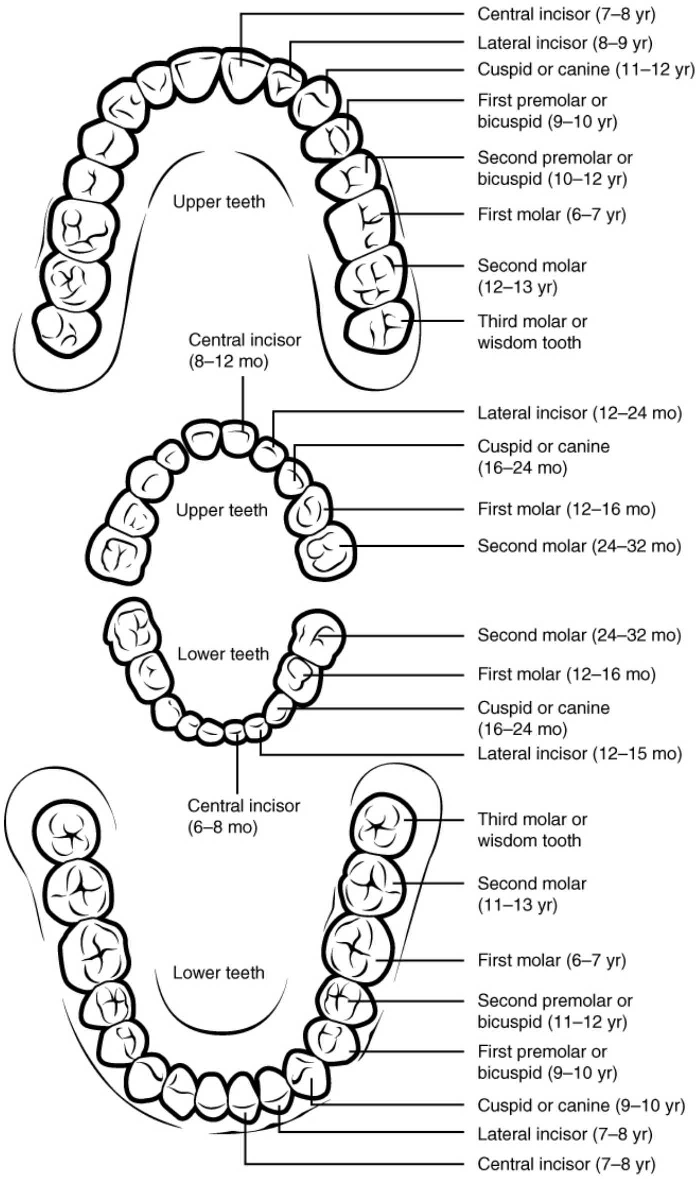
The teeth, or **dentes** (singular = dens), are organs similar to bones that you use to tear, grind, and otherwise mechanically break down food.

Types of Teeth

During the course of your lifetime, you have two sets of teeth (one set of teeth is a **dentition**). Your 20 **deciduous teeth**, or baby teeth, first begin to appear at about 6 months of age. Between approximately age 6 and 12, these teeth are replaced by 32 **permanent teeth**. Moving from the center of the mouth toward the side, these are as follows ([link]):

- The eight **incisors**, four top and four bottom, are the sharp front teeth you use for biting into food.
- The four **cuspids** (or canines) flank the incisors and have a pointed edge (cusp) to tear up food. These fang-like teeth are superb for piercing tough or fleshy foods.
- Posterior to the cuspids are the eight **premolars** (or bicuspids), which have an overall flatter shape with two rounded cusps useful for mashing foods.
- The most posterior and largest are the 12 **molars**, which have several pointed cusps used to crush food so it is ready for swallowing. The third members of each set of three molars, top and bottom, are commonly referred to as the wisdom teeth, because their eruption is commonly delayed until early adulthood. It is not uncommon for wisdom teeth to fail to erupt; that is, they remain impacted. In these cases, the teeth are typically removed by orthodontic surgery.

Permanent and Deciduous Teeth



This figure of two human dentitions shows the arrangement of teeth in the maxilla and mandible, and the relationship between the deciduous and permanent teeth.

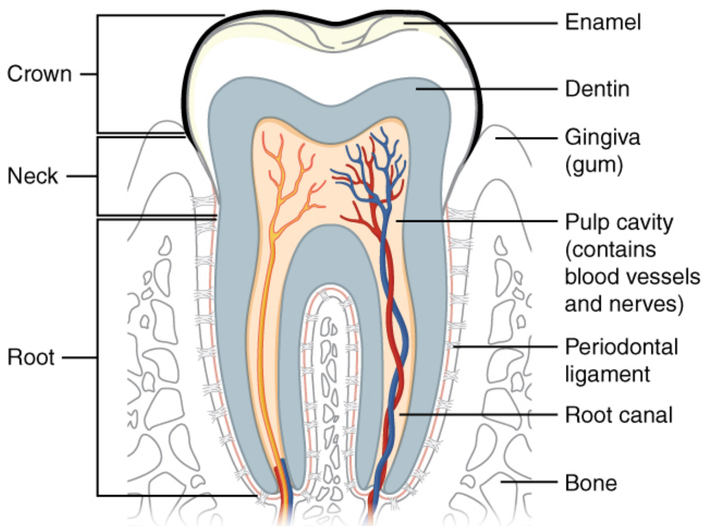
Anatomy of a Tooth

The teeth are secured in the alveolar processes (sockets) of the maxilla and the mandible. **Gingivae** (commonly called the gums) are soft tissues that line the alveolar processes and surround the necks of the teeth. Teeth are also held in their sockets by a connective tissue called the periodontal ligament.

The two main parts of a tooth are the **crown**, which is the portion projecting above the gum line, and the **root**, which is embedded within the maxilla and mandible. Both parts contain an inner **pulp cavity**, containing loose connective tissue through which run nerves and blood vessels. The region of the pulp cavity that runs through the root of the tooth is called the root canal. Surrounding the pulp cavity is **dentin**, a bone-like tissue. In the root of each tooth, the dentin is covered by an even harder bone-like layer called **cementum**. In the crown of each tooth, the dentin is covered by an outer layer of **enamel**, the hardest substance in the body ([link]).

Although enamel protects the underlying dentin and pulp cavity, it is still nonetheless susceptible to mechanical and chemical erosion, or what is known as tooth decay. The most common form, dental caries (cavities) develops when colonies of bacteria feeding on sugars in the mouth release acids that cause soft tissue inflammation and degradation of the calcium crystals of the enamel. The digestive functions of the mouth are summarized in [link].

The Structure of the Tooth



This longitudinal section through a

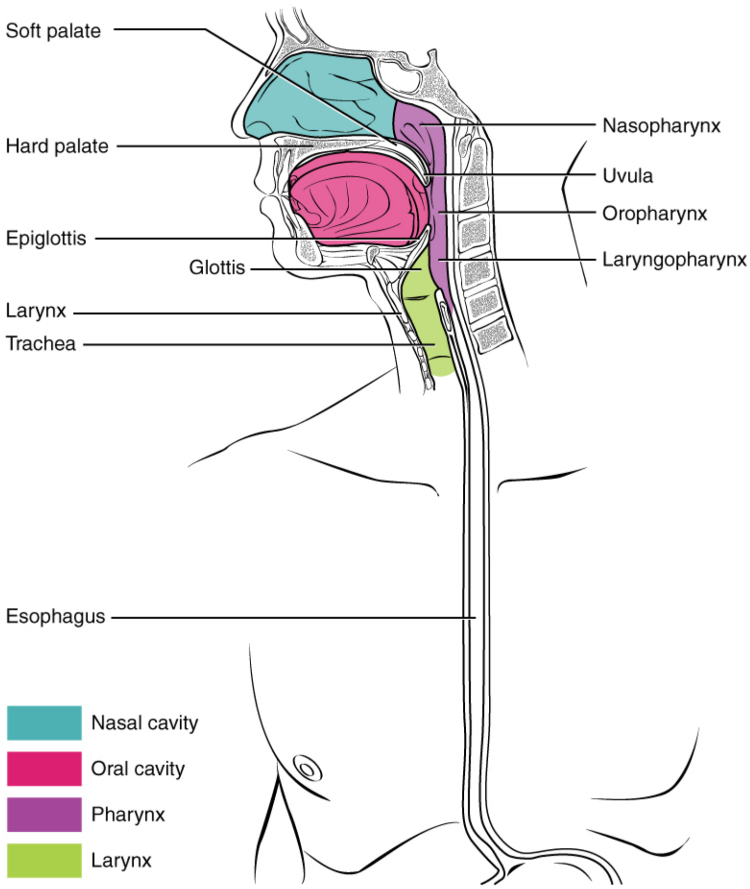
molar in its alveolar socket shows the relationships between enamel, dentin, and pulp.

The Pharynx

The **pharynx** (throat) is involved in both digestion and respiration. It receives food and air from the mouth, and air from the nasal cavities. When food enters the pharynx, involuntary muscle contractions close off the air passageways.

A short tube of skeletal muscle lined with a mucous membrane, the pharynx runs from the posterior oral and nasal cavities to the opening of the esophagus and larynx. It has three subdivisions. The most superior, the nasopharynx, is involved only in breathing and speech. The other two subdivisions, the **oropharynx** and the **laryngopharynx**, are used for both breathing and digestion. The oropharynx begins inferior to the nasopharynx and is continuous below with the laryngopharynx ([link]). The inferior border of the laryngopharynx connects to the esophagus, whereas the anterior portion connects to the larynx, allowing air to flow into the bronchial tree.

Pharynx



The pharynx runs from the nostrils to the esophagus and the larynx.

Usually during swallowing, the soft palate and uvula rise to close off the entrance to the nasopharynx. At the same time, **epiglottis**, folds inferiorly, covering the **glottis** (the opening to the larynx); this process effectively blocks access to the trachea and bronchi. When the food "goes down the wrong way," it goes into the trachea. When food enters the trachea, the reaction is to cough, which usually forces the food up and out of the trachea, and back into the pharynx.

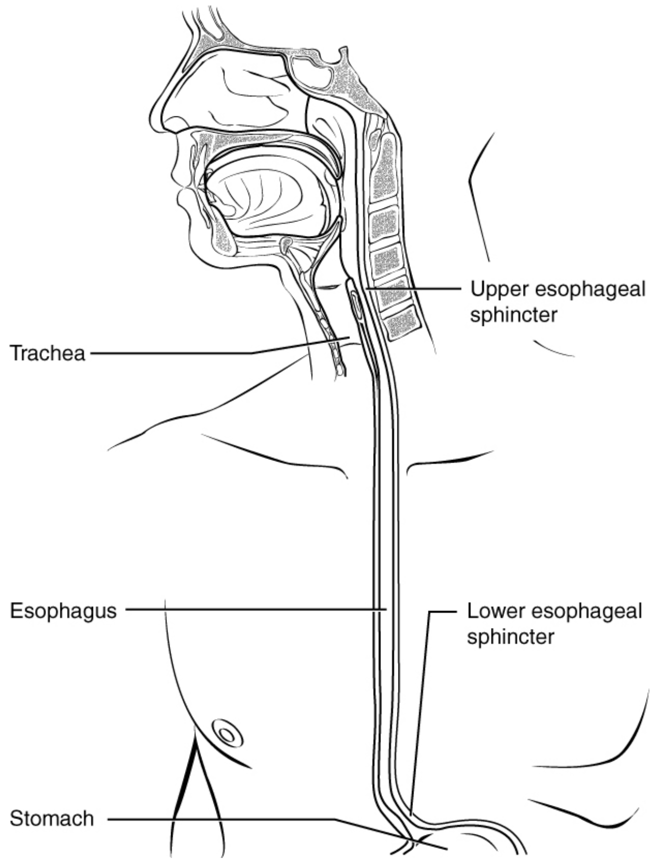
The Esophagus

The **esophagus** is a muscular tube that connects the pharynx to the stomach. It is approximately 25.4 cm (10 in) in length, located posterior to the trachea, and remains in a collapsed form when not engaged in swallowing. As you can see in [link], the esophagus runs a mainly straight route through the mediastinum of the thorax. To enter the abdomen, the esophagus penetrates the diaphragm through an opening called the esophageal hiatus.

Passage of Food through the Esophagus

The **upper esophageal sphincter**, controls the movement of food from the pharynx into the esophagus. Rhythmic waves of peristalsis, which begin in the upper esophagus, propel the bolus of food toward the stomach. Meanwhile, secretions from the esophagus lubricate the esophagus and food. Food passes from the esophagus into the stomach at the **lower esophageal sphincter** (also called the gastroesophageal or cardiac sphincter). Recall that sphincters are muscles that surround tubes and serve as valves, closing the tube when the sphincters contract and opening it when they relax. The lower esophageal sphincter relaxes to let food pass into the stomach, and then contracts to prevent stomach acids from backing up into the esophagus. When the lower esophageal sphincter does not completely close, the stomach's contents can reflux (that is, back up into the esophagus), causing heartburn or **gastroesophageal reflux disease (GERD)**.

Esophagus



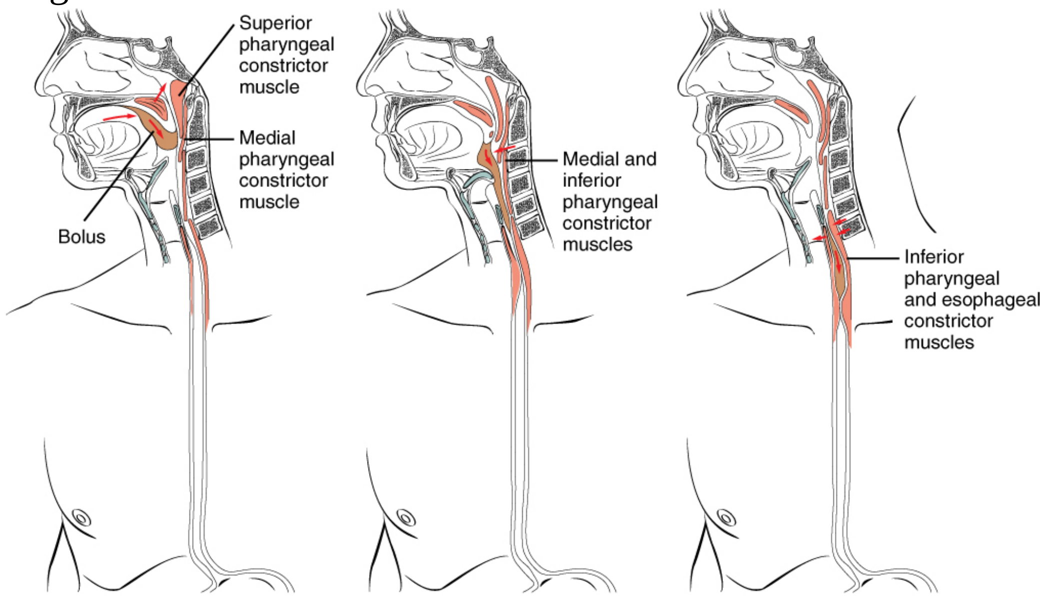
The upper esophageal sphincter controls the movement of food from the pharynx to the esophagus. The lower esophageal sphincter controls the movement of food from the esophagus to the stomach.

Deglutition

Deglutition is another word for swallowing—the movement of food from the mouth to the stomach. The entire process takes about 4 to 8 seconds for solid or semisolid food, and about 1 second for very soft food and liquids. Although this sounds quick and effortless, deglutition is, in fact, a complex process that involves both the skeletal muscle of the tongue and the muscles

of the pharynx and esophagus. It is aided by the presence of mucus and saliva. There are three stages in deglutition: **the voluntary phase, the pharyngeal phase, and the esophageal phase** ([link]).

Deglutition



Deglutition includes the voluntary phase and two involuntary phases: the pharyngeal phase and the esophageal phase.

Chapter Review

In the mouth, the tongue and the teeth begin mechanical digestion, and saliva begins chemical digestion. The pharynx, which plays roles in breathing and vocalization as well as digestion, runs from the nasal and oral cavities superiorly to the esophagus inferiorly (for digestion) and to the larynx anteriorly (for respiration). During deglutition (swallowing), the soft palate rises to close off the nasopharynx, the larynx elevates, and the epiglottis folds over the glottis. The esophagus includes an upper esophageal sphincter made of skeletal muscle, which regulates the movement of food from the pharynx to the esophagus. It also has a lower esophageal sphincter, made of smooth muscle, which controls the passage

of food from the esophagus to the stomach. Cells in the esophageal wall secrete mucus that eases the passage of the food bolus.

References

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Glossary

bolus
: mass of chewed food

cementum
: bone-like tissue covering the root of a tooth

crown
: portion of tooth visible superior to the gum line

cuspid
: (also, canine) pointed tooth used for tearing and shredding food

deciduous tooth
: one of 20 “baby teeth”

deglutition
: three-stage process of swallowing

dens
: tooth

dentin
: bone-like tissue immediately deep to the enamel of the crown or cementum of the root of a tooth

dentition
: set of teeth

enamel
: covering of the dentin of the crown of a tooth

esophagus
: muscular tube that runs from the pharynx to the stomach

fauces
: opening between the oral cavity and the oropharynx

gingiva
: gum

incisor
: midline, chisel-shaped tooth used for cutting into food

labium
: lip

labial frenulum
: midline mucous membrane fold that attaches the inner surface of the lips to the gums

laryngopharynx
: part of the pharynx that functions in respiration and digestion

lingual frenulum
: mucous membrane fold that attaches the bottom of the tongue to the floor of the mouth

lingual lipase
: digestive enzyme from glands in the tongue that acts on triglycerides

lower esophageal sphincter
: smooth muscle sphincter that regulates food movement from the esophagus to the stomach

molar
tooth used for crushing and grinding food

oral cavity
(also, buccal cavity) mouth

oral vestibule
part of the mouth bounded externally by the cheeks and lips, and internally by the gums and teeth

oropharynx
part of the pharynx continuous with the oral cavity that functions in respiration and digestion

palatoglossal arch
muscular fold that extends from the lateral side of the soft palate to the base of the tongue

palatopharyngeal arch
muscular fold that extends from the lateral side of the soft palate to the side of the pharynx

parotid gland
one of a pair of major salivary glands located inferior and anterior to the ears

permanent tooth
one of 32 adult teeth

pharynx
throat

premolar
(also, bicuspid) transitional tooth used for mastication, crushing, and grinding food

pulp cavity
deepest portion of a tooth, containing nerve endings and blood vessels

root
: portion of a tooth embedded in the alveolar processes beneath the gum line

saliva
: aqueous solution of proteins and ions secreted into the mouth by the salivary glands

salivary amylase
: digestive enzyme in saliva that acts on starch

salivary gland
: an exocrine gland that secretes a digestive fluid called saliva

salivation
: secretion of saliva

soft palate
: posterior region of the bottom portion of the nasal cavity that consists of skeletal muscle

sublingual gland
: one of a pair of major salivary glands located beneath the tongue

submandibular gland
: one of a pair of major salivary glands located in the floor of the mouth

tongue
: accessory digestive organ of the mouth, the bulk of which is composed of skeletal muscle

upper esophageal sphincter
: skeletal muscle sphincter that regulates food movement from the pharynx to the esophagus

voluntary phase
: initial phase of deglutition, in which the bolus moves from the mouth to the oropharynx

Digestive System Module 4: The Stomach
By the end of this section, you will be able to:

- Label on a diagram the four main regions of the stomach, its curvatures, and its sphincter
- Identify the four main types of secreting cells in gastric glands, and their important products
- Explain why the stomach does not digest itself
- Describe the mechanical and chemical digestion of food entering the stomach

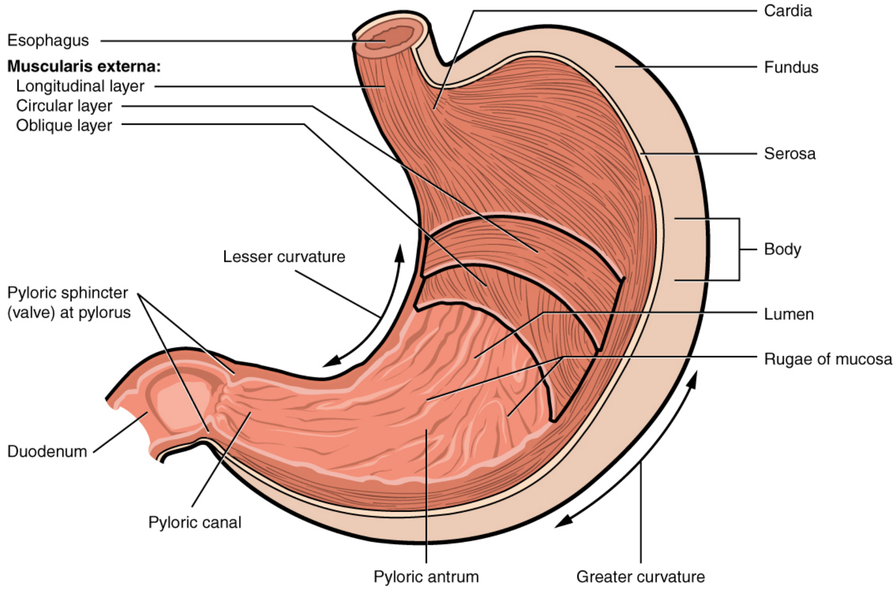
Chemical digestion really gets underway in the stomach. It lies immediately inferior to the esophagus, the stomach links the esophagus to the first part of the small intestine (the duodenum). It can be a highly active structure, contracting and continually changing position and size. These contractions provide mechanical assistance to digestion. The empty stomach is only about the size of your fist, but can stretch to hold as much as 4 liters of food and fluid, or more than 75 times its empty volume, and then return to its resting size when empty.

Popular culture tends to refer to the stomach as the location where all digestion takes place. Of course, this is not true. An important function of the **stomach** is to serve as a temporary holding chamber. You can ingest a meal far more quickly than it can be digested and absorbed by the small intestine. Thus, the stomach holds food and delivers only small amounts into the small intestine at a time. Foods are not processed in the order they are eaten; rather, they are mixed together with digestive juices in the stomach until they are converted into chyme, which is released into the small intestine.

As you will see in the sections that follow, the stomach plays several important roles in chemical digestion, including the continued digestion of carbohydrates and the initial digestion of proteins and fats. Little if any nutrient absorption occurs in the stomach, with the exception of the negligible amount of nutrients in alcohol.

Structure

There are four main regions in the **stomach**: the cardia, fundus, body, and pylorus ([link]). The **cardia** (or cardiac region) is the point where the esophagus connects to the stomach and through which food passes into the stomach. Located inferior to the diaphragm, above and to the left of the cardia, is the dome-shaped **fundus**. Below the fundus is the **body**, the main part of the stomach. The funnel-shaped **pylorus** connects the stomach to the duodenum. connects to the body of the stomach. The narrower end is called the **pyloric canal**, which connects to the duodenum. The smooth muscle **pyloric sphincter** is located at this latter point of connection and controls stomach emptying. In the absence of food, the stomach deflates inward, and its mucosa falls into large folds called **rugae**.
Stomach



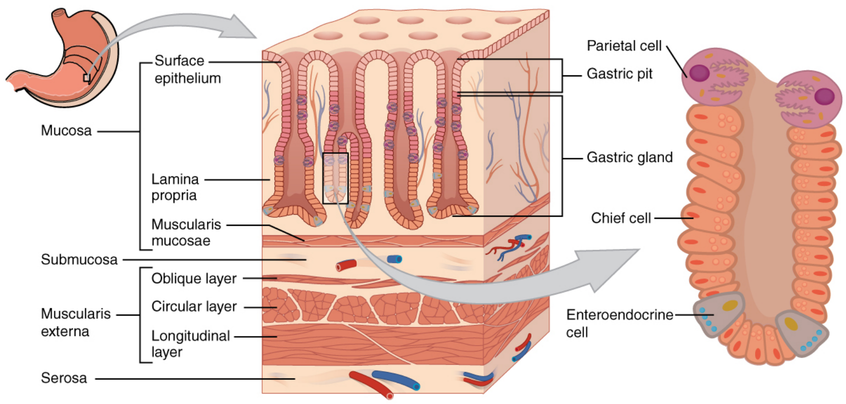
The stomach has four major regions: the cardia, fundus, body, and pylorus. The addition of an inner oblique smooth muscle layer gives the muscularis the ability to vigorously churn and mix food.

The convex lateral surface of the stomach is called the greater curvature; the concave medial border is the lesser curvature. The stomach is held in place by the lesser omentum, which extends from the liver to the lesser curvature, and the greater omentum, which runs from the greater curvature to the posterior abdominal wall.

Histology

he wall of the stomach is made of the same four layers as most of the rest of the alimentary canal, but with adaptations to the mucosa and muscularis for the unique functions of this organ. In addition to the typical circular and longitudinal smooth muscle layers, the muscularis has an third layer of muscle, the **oblique muscle layer** ([link])which allows the stomach to vigorously churn food, mechanically breaking it down into smaller particles.

Histology of the Stomach



The stomach wall is adapted for the functions of the stomach. In the epithelium, gastric pits lead to gastric glands that secrete gastric juice. The gastric glands (one gland is shown enlarged on the right) contain different types of cells that secrete a variety of enzymes, including hydrochloride acid, which activates the protein-digesting enzyme pepsin.

The stomach mucosa's epithelial lining consists only of surface mucus cells, which secrete a protective coat of alkaline mucus. A vast number of **gastric pits** dot the surface of the epithelium, giving it the appearance of a well-used pincushion, and mark the entry to each **gastric gland**, which secretes a complex digestive fluid referred to as **gastric juice**.

Although the walls of the gastric pits are made up primarily of mucus cells, the gastric glands also include chief cells and parietal cells. Cells that make up the area of the pyloris secrete mucus and a number of hormones, including the majority of the stimulatory hormone, **gastrin**. The much larger glands of the fundus and body of the stomach, the site of most chemical digestion, produce most of the gastric secretions. These glands are made up of a variety of secretory cells. These include parietal cells, chief cells, mucous neck cells, and enteroendocrine cells.

Parietal cells—Located primarily in the middle region of the gastric glands are **parietal cells** which produce both **hydrochloric acid (HCl)** and **intrinsic factor**. HCl is responsible for the high acidity (pH 1.5 to 3.5) of the stomach contents and is needed to activate the protein-digesting enzyme, **pepsin**. The acidity also kills much of the bacteria you ingest with food and helps to break down proteins, making them more available for enzymatic digestion. Intrinsic factor is a glycoprotein necessary for the absorption of vitamin B_{12} in the small intestine.

Chief cells—Also located primarily in the gastric glands are **chief cells**, which secrete **pepsinogen**, the inactive substance that will convert to pepsin. HCl is necessary for the conversion of pepsinogen to pepsin. *Enteroendocrine cells*—Finally, **enteroendocrine cells**which are also found in the gastric glands secrete various hormones. Do not take notes on table below.

[link] describes the digestive functions of important hormones secreted by the stomach.

Hormones Secreted by the Stomach				
Hormone	**Production site**	**Production stimulus**	**Target organ**	**Action**
Gastrin	Stomach mucosa, mainly G cells of the pyloric antrum	Presence of peptides and amino acids in stomach	Stomach	Increases secretion by gastric glands; promotes gastric emptying
Gastrin	Stomach mucosa, mainly G cells of the pyloric antrum	Presence of peptides and amino acids in stomach	Small intestine	Promotes intestinal muscle contraction
Gastrin	Stomach mucosa, mainly G cells of the pyloric antrum	Presence of peptides and amino acids in stomach	Ileocecal valve	Relaxes valve

Hormones Secreted by the Stomach				
Hormone	**Production site**	**Production stimulus**	**Target organ**	**Action**
Gastrin	Stomach mucosa, mainly G cells of the pyloric antrum	Presence of peptides and amino acids in stomach	Large intestine	Triggers mass movements
Ghrelin	Stomach mucosa, mainly fundus	Fasting state (levels increase just prior to meals)	Hypothalamus	Regulates food intake, primarily by stimulating hunger and satiety
Histamine	Stomach mucosa	Presence of food in the stomach	Stomach	Stimulates parietal cells to release HCl
Serotonin	Stomach mucosa	Presence of food in the stomach	Stomach	Contracts stomach muscle
Somatostatin	Mucosa of stomach, especially pyloric antrum; also duodenum	Presence of food in the stomach; sympathetic axon stimulation	Stomach	Restricts all gastric secretions, gastric motility, and emptying

Hormones Secreted by the Stomach				
Hormone	**Production site**	**Production stimulus**	**Target organ**	**Action**
Somatostatin	Mucosa of stomach, especially pyloric antrum; also duodenum	Presence of food in the stomach; sympathetic axon stimulation	Pancreas	Restricts pancreatic secretions
Somatostatin	Mucosa of stomach, especially pyloric antrum; also duodenum	Presence of food in the stomach; sympathetic axon stimulation	Small intestine	Reduces intestinal absorption by reducing blood flow

Gastric Secretion

The secretion of gastric juice is controlled by both nerves and hormones. Stimuli in the brain, stomach, and small intestine activate or inhibit gastric juice production. This is why the three phases of gastric secretion are called the cephalic, gastric, and intestinal phases ([link]). However, once gastric secretion begins, all three phases can occur simultaneously. The **cephalic phase** (reflex phase) of gastric secretion, which is relatively brief, takes place before food enters the stomach. The smell, taste, sight, or thought of food triggers this phase. The **gastric phase** of secretion lasts 3 to 4 hours, and is set in motion by local neural and hormonal mechanisms triggered by the entry of food into the stomach. The **intestinal phase** of gastric secretion has a major role in regulating the emptying of the stomach into the small intestine.

The Mucosal Barrier

The mucosa of the stomach is exposed to the highly corrosive acidity of gastric juice. Gastric enzymes that can digest protein can also digest the stomach itself. The stomach is protected from self-digestion by the **mucosal barrier**. This barrier has several components. First, the stomach wall is covered by a thick coating of bicarbonate-rich mucus. This mucus forms a physical barrier, and its bicarbonate ions neutralize acid.

Stem cells quickly produce new stomach cells. In fact, the surface epithelium of the stomach is completely replaced every 3 to 6 days.

Digestive Functions of the Stomach

Mechanical Digestion

Within a few moments after food after enters your stomach, mixing waves begin to occur at intervals of approximately 20 seconds. A **mixing wave** is a unique type of peristalsis that mixes and softens the food with gastric juices to create chyme. The pylorus acts as a filter, permitting only liquids and small food particles to pass through pyloric sphincter in a process called **gastric emptying**

Gastric emptying is regulated by both the stomach and the duodenum. The presence of chyme in the duodenum activates receptors that inhibit gastric secretion. This prevents additional chyme from being released by the stomach before the duodenum is ready to process it.

Chemical Digestion

The fundus plays an important role, because it stores both undigested food and gases that are released during the process of chemical digestion. Food may sit in the fundus of the stomach for a while before being mixed with the chyme. While the food is in the fundus, the digestive activities of salivary amylase continue until the food begins mixing with the acidic chyme. Ultimately, mixing waves incorporate this food with the chyme, the acidity of which inactivates salivary amylase. Its numerous digestive functions notwithstanding, there is only one stomach function necessary to life: the production of intrinsic factor. The intestinal absorption of vitamin B_{12}, which is necessary for both the production of mature red blood cells and normal neurological functioning, cannot occur without intrinsic factor.

The contents of the stomach are completely emptied into the duodenum within 2 to 4 hours after you eat a meal. Different types of food take different amounts of time to process. Foods heavy in carbohydrates empty fastest, followed by high-protein foods. Meals with a high fat content remain in the stomach the longest. Since enzymes in the small intestine digest fats slowly, food can stay in the stomach for 6 hours or longer when the duodenum is processing fatty chyme. However, note that this is still a fraction of the 24 to 72 hours that full digestion typically takes from start to finish.

Chapter Review

The stomach participates in all digestive activities except ingestion and defecation. It vigorously churns food. It secretes gastric juices that break down food and absorbs certain drugs, including aspirin and some alcohol. The stomach begins the digestion of protein and continues the digestion of carbohydrates and fats. It stores food as an acidic liquid called chyme, and releases it gradually into the small intestine through the pyloric sphincter.

Glossary

body
: mid-portion of the stomach

cardia
: (also, cardiac region) part of the stomach surrounding the cardiac orifice (esophageal hiatus)

cephalic phase
: (also, reflex phase) initial phase of gastric secretion that occurs before food enters the stomach

chief cell
: gastric gland cell that secretes pepsinogen

enteroendocrine cell
: gastric gland cell that releases hormones

fundus
: dome-shaped region of the stomach above and to the left of the cardia

G cell
: gastrin-secreting enteroendocrine cell

gastric emptying
: process by which mixing waves gradually cause the release of chyme into the duodenum

gastric gland
: gland in the stomach mucosal epithelium that produces gastric juice

gastric phase
: phase of gastric secretion that begins when food enters the stomach

gastric pit
: narrow channel formed by the epithelial lining of the stomach mucosa

gastrin
peptide hormone that stimulates secretion of hydrochloric acid and gut motility

hydrochloric acid (HCl)
digestive acid secreted by parietal cells in the stomach

intrinsic factor
glycoprotein required for vitamin B_{12} absorption in the small intestine

intestinal phase
phase of gastric secretion that begins when chyme enters the intestine

mixing wave
unique type of peristalsis that occurs in the stomach

mucosal barrier
protective barrier that prevents gastric juice from destroying the stomach itself

mucous neck cell
gastric gland cell that secretes a uniquely acidic mucus

parietal cell
gastric gland cell that secretes hydrochloric acid and intrinsic factor

pepsinogen
inactive form of pepsin

pyloric antrum
wider, more superior part of the pylorus

pyloric canal
narrow, more inferior part of the pylorus

pyloric sphincter
sphincter that controls stomach emptying

pylorus
lower, funnel-shaped part of the stomach that is continuous with the duodenum

ruga
fold of alimentary canal mucosa and submucosa in the empty stomach and other organs

stomach

alimentary canal organ that contributes to chemical and mechanical digestion of food from the esophagus before releasing it, as chyme, to the small intestine

Digestive System Module 5: The Small and Large Intestines
By the end of this section, you will be able to:

- Compare and contrast the location and gross anatomy of the small and large intestines
- Identify three main adaptations of the small intestine wall that increase its absorptive capacity
- Describe the mechanical and chemical digestion of chyme upon its release into the small intestine
- List three features unique to the wall of the large intestine and identify their contributions to its function
- Identify the beneficial roles of the bacterial flora in digestive system functioning
- Trace the pathway of food waste from its point of entry into the large intestine through its exit from the body as feces

The word intestine is derived from a Latin root meaning “internal,” and indeed, the two organs together nearly fill the interior of the abdominal cavity. In addition, called the small and large bowel, or colloquially the “guts,” they constitute the greatest mass and length of the alimentary canal and, with the exception of ingestion, perform all digestive system functions.

The Small Intestine

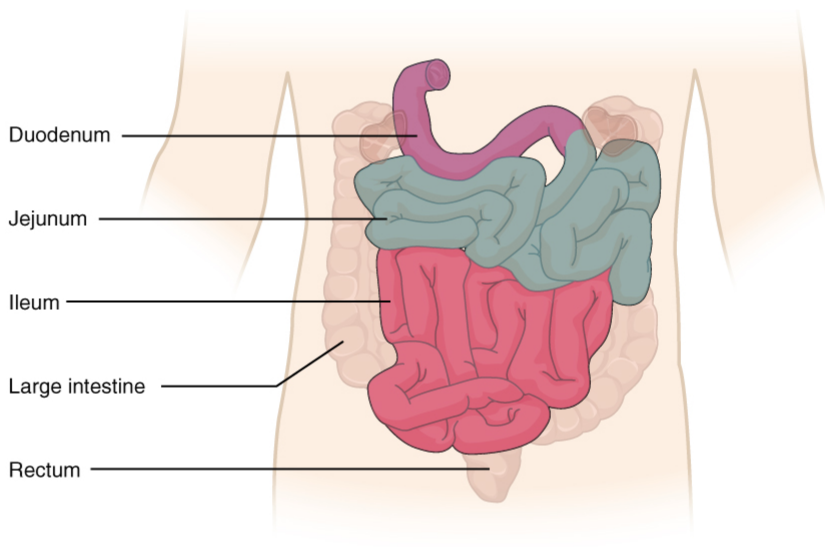
Chyme released from the stomach enters the **small intestine**, which is the primary digestive organ in the body. Not only is this where most digestion occurs, it is also where practically all absorption occurs. The longest part of the alimentary canal, the small intestine is about 10 feet long in a living person . Since this makes it about five times longer than the large intestine, you might wonder why it is called “small.” In fact, its name derives from its relatively smaller diameter of only about 1 inch, compared with 3 inch for the large intestine. As we’ll see shortly, in addition to its length, the folds and projections of the lining of the small intestine work to give it an enormous surface area, which is approximately 200 m^2, more than 100 times the surface area of your skin. This large surface area is necessary for complex processes of digestion and absorption that occur within it.

Structure

The coiled tube of the small intestine is subdivided into three regions. From the stomach to large intestine, these are the **duodenum, jejunum, and ileum** ([link]).

The shortest region is the 10 inch **duodenum**, which begins at the pyloric sphincter. Just past the pyloric sphincter is the **duodenal papilla**. Located in the duodenal wall, it is where the bile duct (through which bile passes from the liver) and the **main pancreatic duct** (through which pancreatic juice passes from the pancreas) join the duodenum. The **sphincter of Oddi** regulates the flow of both bile and pancreatic juice from the papilla into the duodenum. The second part of the small intestine, the **jejunum** is about 3 feet long and runs from the duodenum to the ileum. The **ileum** is the longest part of the small intestine, measuring about 6 feet in length. The ileum joins the cecum, the first portion of the large intestine, at the **ileocecal sphincter** (or valve). The large intestine frames these three parts of the small intestine.

Small Intestine

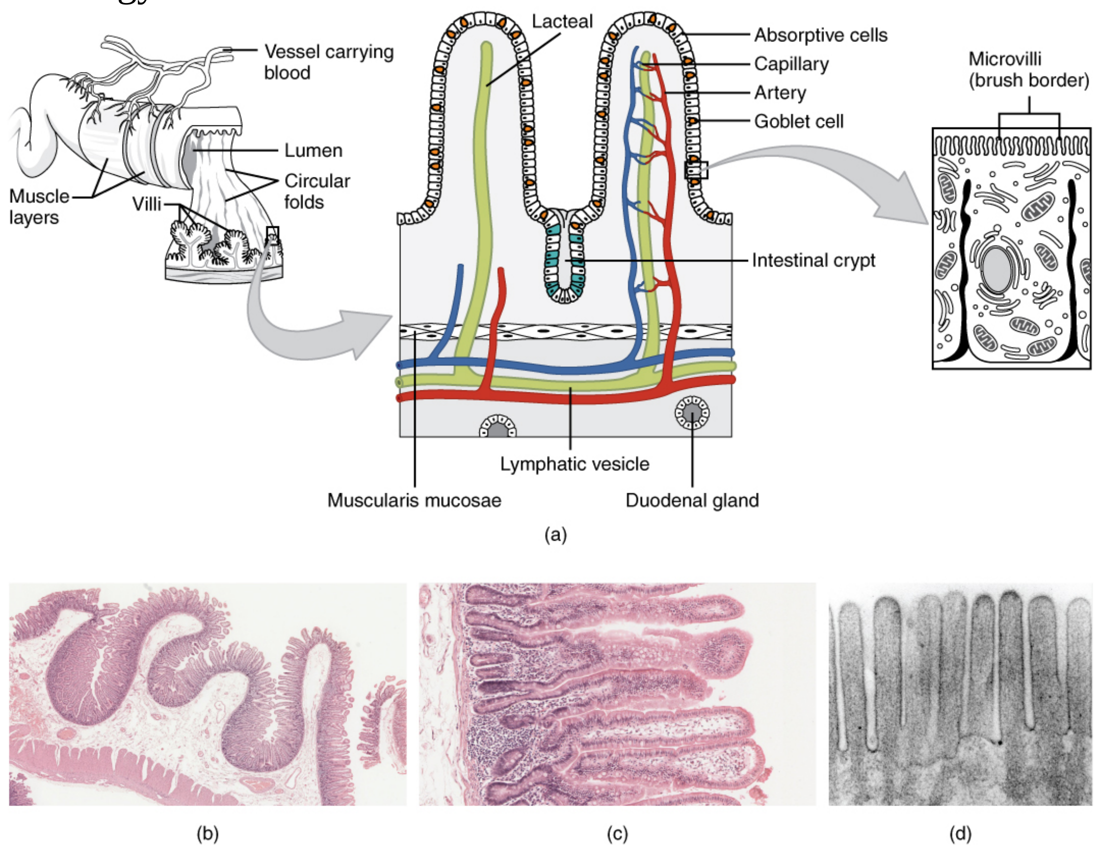


The three regions of the small intestine are the duodenum, jejunum, and ileum.

Histology

The wall of the small intestine is composed of the same four layers typically present in the alimentary system. However, three features of the mucosa and submucosa are unique. These features, which increase the absorptive surface area of the small intestine more than 600-fold, include circular folds, villi, and microvilli ([link]). These adaptations are most abundant in the first two-thirds of the small intestine, where the majority of absorption occurs.

Histology of the Small Intestine



(a) The absorptive surface of the small intestine is vastly enlarged by the presence of circular folds, villi, and microvilli. (b) Micrograph of the circular folds. (c) Micrograph of the villi. (d) Electron micrograph of the microvilli. From left to right, LM x 56, LM x 508, EM x 196,000. (credit b-d: Micrograph provided by the Regents of University of Michigan Medical School © 2012)

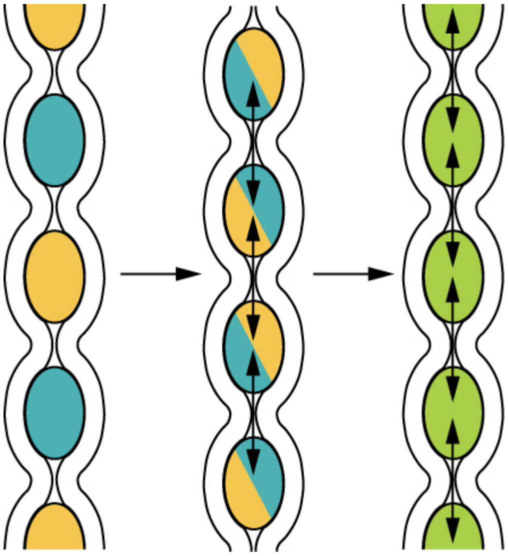
Adaptations to Increase Surface Area

There are three structural adaptations to the small intestine that increase the amount of area for food to be absorbed. A **circular fold** is a deep ridge in the mucosa and submucosa. Beginning near the first part of the duodenum and ending near the middle of the ileum, these folds increase absorption. Their shape causes the chyme to spiral, rather than move in a straight line, through the small intestine. Spiraling slows the movement of chyme and provides the time needed for nutrients to be fully absorbed. Within the circular folds are small (0.5–1 mm long) hairlike projections called **villi** (singular = villus) that give the mucosa a furry texture. There are about 20 to 40 villi per square millimeter, increasing the surface area of the epithelium tremendously. **Microvilli** (singular = microvillus) are much smaller (1 µm) than villi. They are surface extensions of the plasma membrane of the mucosa's epithelial cells. Although their small size makes it difficult to see each microvillus, their combined microscopic appearance suggests a mass of bristles, which is termed the **brush border**. There are an estimated 200 million microvilli per square millimeter of small intestine, greatly expanding the surface area of the plasma membrane and thus greatly enhancing absorption.

Mechanical Digestion in the Small Intestine

The movement of intestinal smooth muscles includes both segmentation and a form of peristalsis called migrating motility complexes. The kind of peristaltic mixing waves seen in the stomach are not observed here.

The smooth muscle layer of the small intestine is responsible for **segmentation**.If you could see into the small intestine when it was going through segmentation, it would look as if the contents were being shoved incrementally back and forth. It combines the chyme with digestive juices and pushes food particles against the intestinal wall to be absorbed.
Segmentation



Segmentation separates chyme and then pushes it back together, mixing it and providing time for digestion and absorption.

Chemical Digestion in the Small Intestine

The digestion of proteins and carbohydrates, which partially occurs in the stomach, is completed in the small intestine with the aid of intestinal and pancreatic juices. Lipids arrive in the intestine largely undigested, so much of the focus here is on lipid digestion, which is facilitated by bile. Moreover, intestinal juice combines with pancreatic juice to provide a liquid medium that facilitates absorption. The intestine is also where most water is absorbed, via osmosis. The small intestine's absorptive cells also produce digestive enzymes.

The Large Intestine

The **large intestine** is the terminal part of the alimentary canal. The primary function of this organ is to finish absorption of nutrients and water, synthesize certain vitamins, form feces, and eliminate feces from the body.

Structure

The large intestine runs from the appendix to the anus. It frames the small intestine on three sides. Despite its being about one-half as long as the small intestine, it is called large because it is more than twice the diameter of the small intestine, about 3 inches. The large intestine is subdivided into four main regions: the cecum, the colon, the rectum, and the anus. The ileocecal valve, located at the opening between the ileum and the large intestine, controls the flow of chyme from the small intestine to the large intestine.

Subdivisions

Cecum

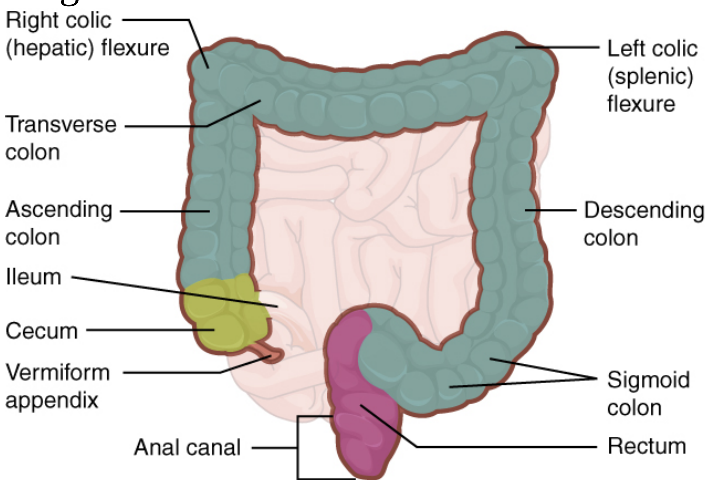
The first part of the large intestine is the **cecum**, a sac-like structure that is suspended inferior to the ileocecal valve. It is about 2.4 inches long, receives the contents of the ileum, and continues the absorption of water and salts. The **appendix** is a winding tube that attaches to the cecum. Although the 3-inch long appendix contains lymphoid tissue, suggesting an immune function, this organ is generally considered **vestigial** (no longer useful). However, at least one recent report suggests a survival advantage provided by the appendix: In illness, the appendix may serve as a bacterial reservoir to repopulate the bacteria after the illness.

Colon

The cecum blends seamlessly with the **colon**. Upon entering the colon, the food residue first travels up the **ascending colon** on the right side of the

abdomen. At the inferior surface of the liver, the colon bends to form the **right colic flexure** (hepatic flexure) and becomes the **transverse colon**. Food residue passing through the transverse colon travels across to the left side of the abdomen, where the colon angles sharply immediately inferior to the spleen, at the **left colic flexure** (splenic flexure). From there, food residue passes through the **descending colon**, which runs down the left side of the abdominal wall. After entering the pelvis it becomes the s-shaped **sigmoid colon**.

Large Intestine



The large intestine includes the cecum, colon, and rectum.

Rectum and Anal Canal

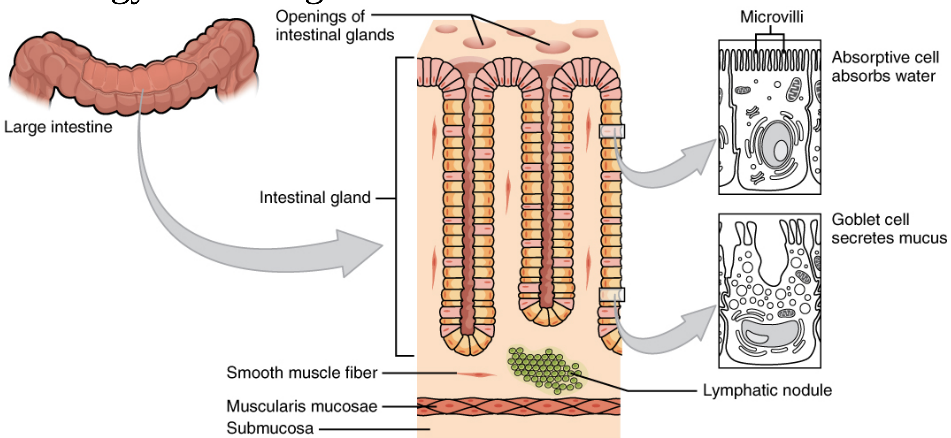
Food residue leaving the sigmoid colon enters the **rectum** in the pelvis. The final 8 inches of the alimentary canal, the rectum extends to the sacrum and coccyx. The rectum stores formed feces until the body is ready to expel the waste. Finally, food residue reaches the last part of the large intestine, the **anal canal** which opens to the exterior of the body at the anus. The anal canal includes two sphincters. The **internal anal sphincter** is made of smooth muscle, and its contractions are involuntary. The **external anal**

sphincter is made of skeletal muscle, which is under voluntary control. Except when defecating, both usually remain closed.

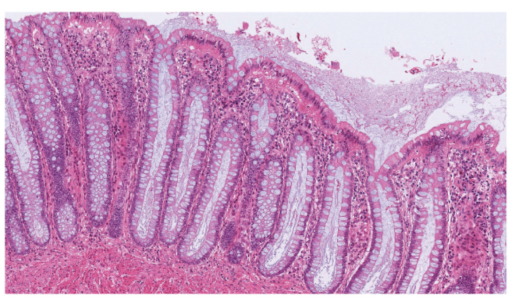
Histology

There are several notable differences between the walls of the large and small intestines ([link]). For example, few enzyme-secreting cells are found in the wall of the large intestine, and there are no circular folds or villi. There is an increased number of mucus producing **goblet cells** . These goblet cells secrete mucus that eases the movement of feces and protects the intestine.

Histology of the large Intestine



(a)



(b)

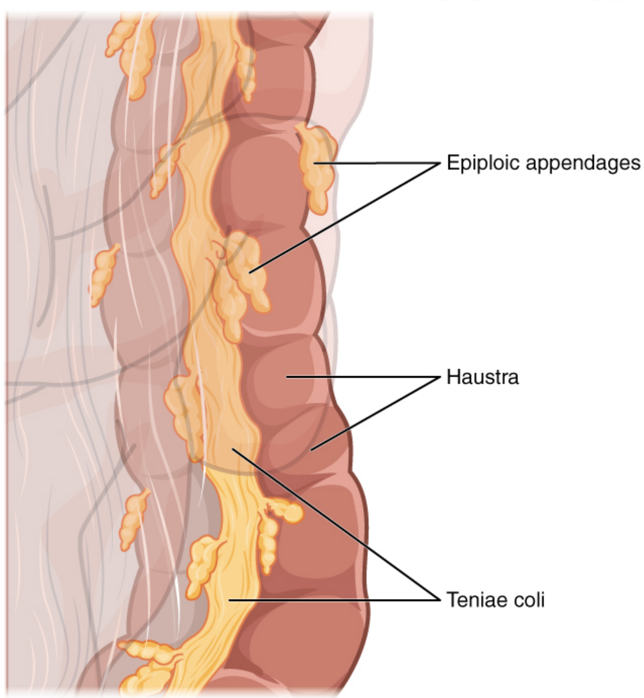
(a) The histologies of the large intestine and small intestine (not shown) are adapted for the digestive functions of each organ. (b) This micrograph shows the colon's simple columnar epithelium and goblet cells. LM x 464. (credit b: Micrograph provided by the

Regents of University of Michigan Medical School © 2012)

Anatomy

Three features are unique to the large intestine: teniae coli, haustra, and epiploic appendages ([link]). The **teniae coli** are three bands of smooth muscle that make up the longitudinal muscle layer of the muscularis of the large intestine, except at its terminal end. Tonic contractions of the teniae coli bunch up the colon into a succession of pouches called **haustra** (singular = hostrum), which are responsible for the wrinkled appearance of the colon. Attached to the teniae coli are small, fat-filled sacs of visceral peritoneum called **epiploic appendages**. The purpose of these is unknown. Although the rectum and anal canal have neither teniae coli nor haustra, they do have well-developed layers of muscularis that create the strong contractions needed for defecation.

Teniae Coli, Haustra, and Epiploic Appendages



Bacterial Flora

Most bacteria that enter the alimentary canal are killed by lysozyme, HCl, or protein-digesting enzymes. However, trillions of bacteria live within the large intestine and are referred to as the **bacterial flora**. Most of the more than 700 species of these bacteria cause no harm as long as they stay in the gut lumen. In fact, many facilitate chemical digestion and absorption.

Digestive Functions of the Large Intestine

The residue of chyme that enters the large intestine contains few nutrients except water, which is reabsorbed as the residue lingers in the large intestine, typically for 12 to 24 hours. Thus, it may not surprise you that the large intestine can be completely removed without significantly affecting digestive functioning. For example, in severe cases of inflammatory bowel disease, the large intestine can be removed by a procedure known as a colectomy. Often, a new fecal pouch can be crafted from the small intestine and sutured to the anus, but if not, an ileostomy can be created by bringing the distal ileum through the abdominal wall, allowing the watery chyme to be collected in a bag-like adhesive appliance.

Absorption, Feces Formation, and Defecation

The small intestine absorbs about 90 percent of the water you ingest (either as liquid or within solid food). The large intestine absorbs most of the remaining water, a process that converts the liquid chyme residue into semisolid **feces** ("stool"). Feces is composed of undigested food residues, unabsorbed digested substances, millions of bacteria, old epithelial cells from the GI mucosa, inorganic salts, and enough water to let it pass smoothly out of the body. Of every 500 mL (17 ounces) of food residue that enters the cecum each day, about 150 mL (5 ounces) become feces.

Feces are eliminated through contractions of the rectal muscles. You help this process by a voluntary procedure called **Valsalva's maneuver**, in

which you increase intra-abdominal pressure by contracting your diaphragm and abdominal wall muscles, and closing your glottis.

If defecation is delayed for an extended time, additional water is absorbed, making the feces firmer and potentially leading to constipation. On the other hand, if the waste matter moves too quickly through the intestines, not enough water is absorbed, and diarrhea can result. This can be caused by the ingestion of foodborne pathogens. In general, diet, health, and stress determine the frequency of bowel movements. The number of bowel movements varies greatly between individuals, ranging from two or three per day to three or four per week.

Chapter Review

The three main regions of the small intestine are the duodenum, the jejunum, and the ileum. The small intestine is where digestion is completed and virtually all absorption occurs. These two activities are facilitated by structural adaptations that increase the mucosal surface area by 600-fold, including circular folds, villi, and microvilli. There are around 200 million microvilli per square millimeter of small intestine, which contain brush border enzymes that complete the digestion of carbohydrates and proteins. Combined with pancreatic juice, intestinal juice provides the liquid medium needed to further digest and absorb substances from chyme. The small intestine is also the site of unique mechanical digestive movements. Segmentation moves the chyme back and forth, increasing mixing and opportunities for absorption. Migrating motility complexes propel the residual chyme toward the large intestine.

The main regions of the large intestine are the cecum, the colon, and the rectum. The large intestine absorbs water and forms feces, and is responsible for defecation. Bacterial flora break down additional carbohydrate residue, and synthesize certain vitamins. The mucosa of the large intestinal wall is generously endowed with goblet cells, which secrete mucus that eases the passage of feces. The entry of feces into the rectum activates the defecation reflex.

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Glossary

anal canal
: final segment of the large intestine

anal column
: long fold of mucosa in the anal canal

anal sinus
: recess between anal columns

appendix
: (vermiform appendix) coiled tube attached to the cecum

ascending colon
: first region of the colon

bacterial flora
: bacteria in the large intestine

brush border

fuzzy appearance of the small intestinal mucosa created by microvilli

cecum
pouch forming the beginning of the large intestine

circular fold
(also, plica circulare) deep fold in the mucosa and submucosa of the small intestine

colon
part of the large intestine between the cecum and the rectum

descending colon
part of the colon between the transverse colon and the sigmoid colon

duodenal gland
(also, Brunner’s gland) mucous-secreting gland in the duodenal submucosa

duodenum
first part of the small intestine, which starts at the pyloric sphincter and ends at the jejunum

epiploic appendage
small sac of fat-filled visceral peritoneum attached to teniae coli

external anal sphincter
voluntary skeletal muscle sphincter in the anal canal

feces
semisolid waste product of digestion

flatus
gas in the intestine

gastrocolic reflex
propulsive movement in the colon activated by the presence of food in the stomach

gastroileal reflex
: long reflex that increases the strength of segmentation in the ileum

haustrum
: small pouch in the colon created by tonic contractions of teniae coli

haustral contraction
: slow segmentation in the large intestine

hepatopancreatic ampulla
: (also, ampulla of Vater) bulb-like point in the wall of the duodenum where the bile duct and main pancreatic duct unite

hepatopancreatic sphincter
: (also, sphincter of Oddi) sphincter regulating the flow of bile and pancreatic juice into the duodenum

ileocecal sphincter
: sphincter located where the small intestine joins with the large intestine

ileum
: end of the small intestine between the jejunum and the large intestine

internal anal sphincter
: involuntary smooth muscle sphincter in the anal canal

intestinal gland
: (also, crypt of Lieberkühn) gland in the small intestinal mucosa that secretes intestinal juice

intestinal juice
: mixture of water and mucus that helps absorb nutrients from chyme

jejunum
: middle part of the small intestine between the duodenum and the ileum

lacteal
: lymphatic capillary in the villi

large intestine
terminal portion of the alimentary canal

left colic flexure
(also, splenic flexure) point where the transverse colon curves below the inferior end of the spleen

main pancreatic duct
(also, duct of Wirsung) duct through which pancreatic juice drains from the pancreas

major duodenal papilla
point at which the hepatopancreatic ampulla opens into the duodenum

mass movement
long, slow, peristaltic wave in the large intestine

mesoappendix
mesentery of the appendix

microvillus
small projection of the plasma membrane of the absorptive cells of the small intestinal mucosa

migrating motility complex
form of peristalsis in the small intestine

motilin
hormone that initiates migrating motility complexes

pectinate line
horizontal line that runs like a ring, perpendicular to the inferior margins of the anal sinuses

rectal valve
one of three transverse folds in the rectum where feces is separated from flatus

rectum

part of the large intestine between the sigmoid colon and anal canal

right colic flexure
(also, hepatic flexure) point, at the inferior surface of the liver, where the ascending colon turns abruptly to the left

saccharolytic fermentation
anaerobic decomposition of carbohydrates

sigmoid colon
end portion of the colon, which terminates at the rectum

small intestine
section of the alimentary canal where most digestion and absorption occurs

tenia coli
one of three smooth muscle bands that make up the longitudinal muscle layer of the muscularis in all of the large intestine except the terminal end

transverse colon
part of the colon between the ascending colon and the descending colon

Valsalva’s maneuver
voluntary contraction of the diaphragm and abdominal wall muscles and closing of the glottis, which increases intra-abdominal pressure and facilitates defecation

villus
projection of the mucosa of the small intestine

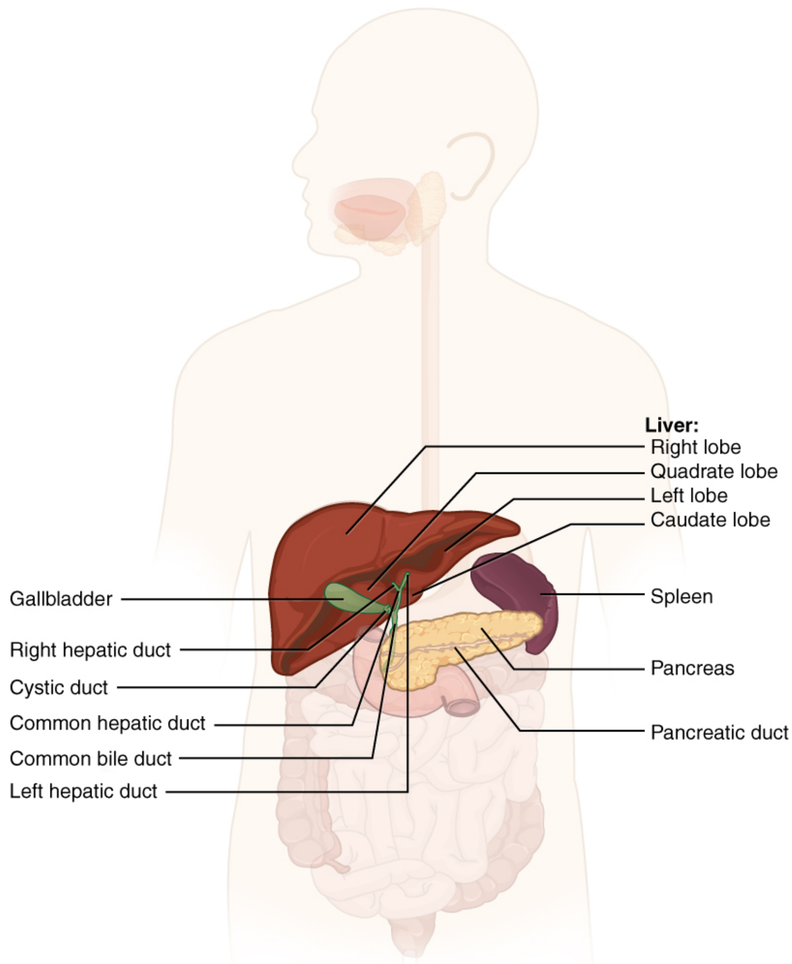
Digestive System Module 6: Accessory Organs in Digestion: The Liver, Pancreas, and Gallbladder

By the end of this section, you will be able to:

- State the main digestive roles of the liver, pancreas, and gallbladder
- Identify three main features of liver histology that are critical to its function
- Discuss the composition and function of bile
- Identify the major types of enzymes and buffers present in pancreatic juice

Chemical digestion in the small intestine relies on the activities of three accessory digestive organs: the liver, pancreas, and gallbladder ([link]). The digestive role of the liver is to produce bile and export it to the duodenum. The gallbladder primarily stores, concentrates, and releases bile. The pancreas produces pancreatic juice, which contains digestive enzymes and bicarbonate ions, and delivers it to the duodenum.

Accessory Organs



The liver, pancreas, and gallbladder are considered accessory digestive organs, but their roles in the digestive system are vital.

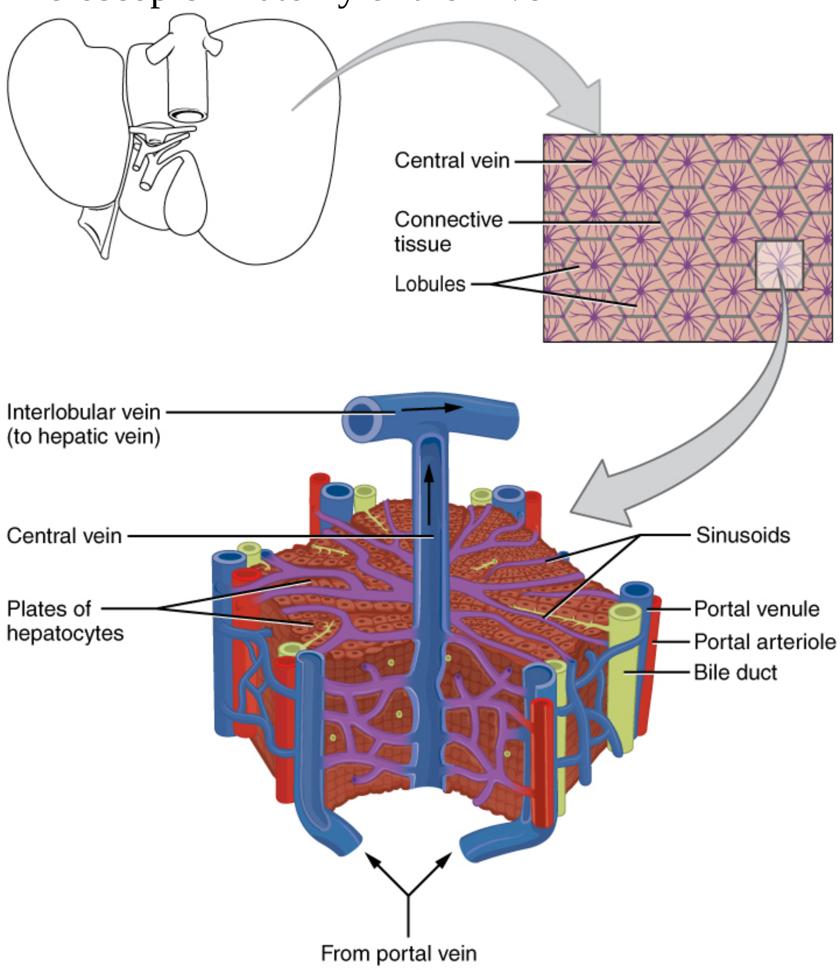
The Liver

The **liver** is the largest gland in the body, weighing about three pounds in an adult. It is also one of the most important organs. In addition to being an accessory digestive organ, it plays a number of roles in metabolism and regulation. The liver lies inferior to the diaphragm in the right upper quadrant of the abdominal cavity and receives protection from the surrounding ribs. The liver is divided into two primary lobes: a large right

lobe and a much smaller left lobe. The liver is connected to the abdominal wall and diaphragm by five ligaments. The **falciform ligament** is visible on the midline of the surface of the liver.

The liver has two blood supplies. The first comes via the **hepatic artery** and brings fresh oxygenated blood to the liver, in the same way that oxygenated blood is supplied to all the body's organs. The second blood supply is delivered via the **hepatic portal vein**. This vein is a major component of the **hepatic portal system**. This system brings blood containing recently absorbed nutrients from the small intestine. The liver monitors the blood coming from the small intestine. The liver will destroy toxins and other undesirable molecules before allowing the blood to return to the heart for distribution to the whole body.

Microscopic Anatomy of the Liver



The liver receives oxygenated blood from the

hepatic artery and nutrient-rich deoxygenated blood from the hepatic portal vein.

Histology

A **hepatocyte** is the liver’s main cell type, accounting for around 80 percent of the liver's volume. These cells play a role in a wide variety of secretory, metabolic, and endocrine functions. Between adjacent hepatocytes, bile manufactured by the liver accumulates and is directed to the **right and left hepatic ducts**, which merge to form the **common hepatic duct** which delivers bile to the gallbladder. This duct then joins with the cystic duct from the gallbladder, forming the **common bile duct** through which bile flows into the small intestine.

Bile

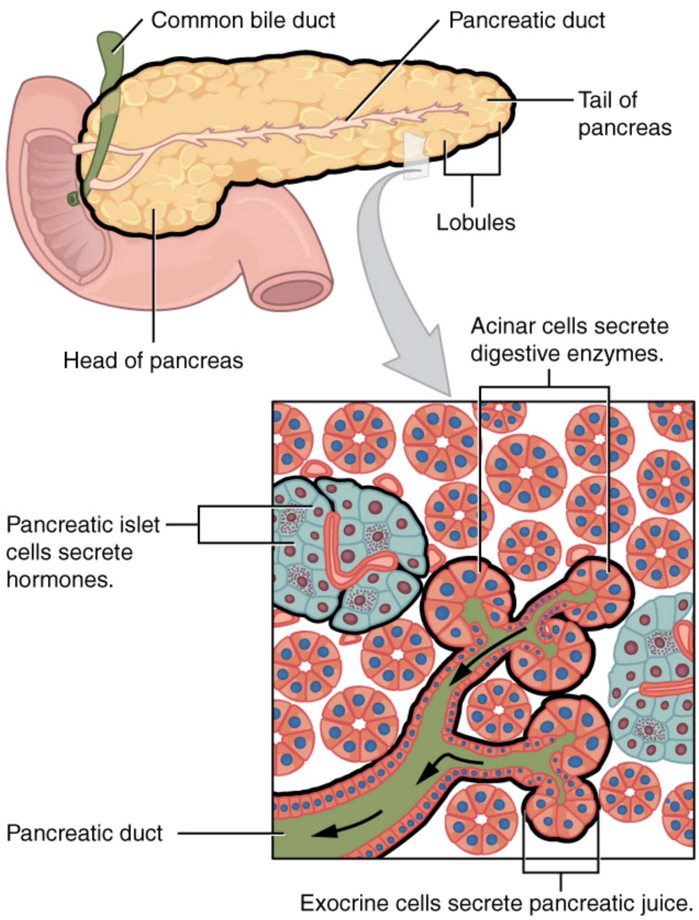
Recall that lipids do not dissolve in water. Thus, before they can be digested in the watery environment of the small intestine, large lipid globules must be broken down into smaller lipid globules, a process called **emulsification**. **Bile** is a mixture secreted by the liver to accomplish the emulsification of lipids in the small intestine. Hepatocytes secrete about one liter of bile each day. A yellow-brown or yellow-green solution, bile is a mixture of water, bile salts, bile pigments, cholesterol, and other molecules. The bile salts are most critical to emulsification. Emulsification results in the large lipid globules being pulled apart into many tiny lipid fragments. This change dramatically increases the surface area available for lipid-digesting enzyme activity. This is the same way dish soap works on fats mixed with water.

Hepatocytes work non-stop, but bile production increases when fatty chyme enters the duodenum and stimulates the secretion of the gut hormone secretin. Between meals, bile is produced but conserved. Bile is diverted to the gallbladder, where it is concentrated and stored until the next meal.

The Pancreas

The soft, oblong, glandular **pancreas** lies nestled into the “c-shaped” curvature of the duodenum with the body extending to the left. It is a curious mix of exocrine (secreting digestive enzymes) and endocrine (releasing hormones into the blood) functions ([link]). The exocrine part of the pancreas arises as little grape-like cell clusters, each called an **acinus** (plural = acini), located at the terminal ends of pancreatic ducts. These acinar cells secrete enzyme-rich **pancreatic juice** into tiny merging ducts that form two dominant ducts. The larger duct fuses with the common bile duct (carrying bile from the liver and gallbladder) just before entering the duodenum via a common opening. Scattered through the sea of exocrine acini are small islands of endocrine cells, the **islets of Langerhans**. These vital cells produce the hormones insulin, glucagon, and other crucial hormones.

Exocrine and Endocrine Pancreas



The pancreas has a head, a body, and a tail. It delivers pancreatic juice to the duodenum through the pancreatic duct.

Pancreatic Juice

The pancreas produces over a liter of pancreatic juice each day. Unlike bile, it is clear and composed mostly of water along with some salts, sodium bicarbonate, and several digestive enzymes. Sodium bicarbonate is responsible for the slight alkalinity of pancreatic juice, which serves to buffer the acidic gastric juice in chyme, inactivate pepsin from the stomach, and create an optimal environment for the activity of pH-sensitive digestive enzymes in the small intestine. Pancreatic enzymes are active in the digestion of sugars, proteins, and fats.

The pancreas produces protein-digesting enzymes in their inactive forms. These enzymes are activated in the duodenum. If produced in an active form, they would digest the pancreas (which is exactly what occurs in the disease, pancreatitis).The enzymes that digest starch (amylase), fat (lipase), and nucleic acids (nuclease) are secreted in their active forms, since they do not attack the pancreas as do the protein-digesting enzymes.

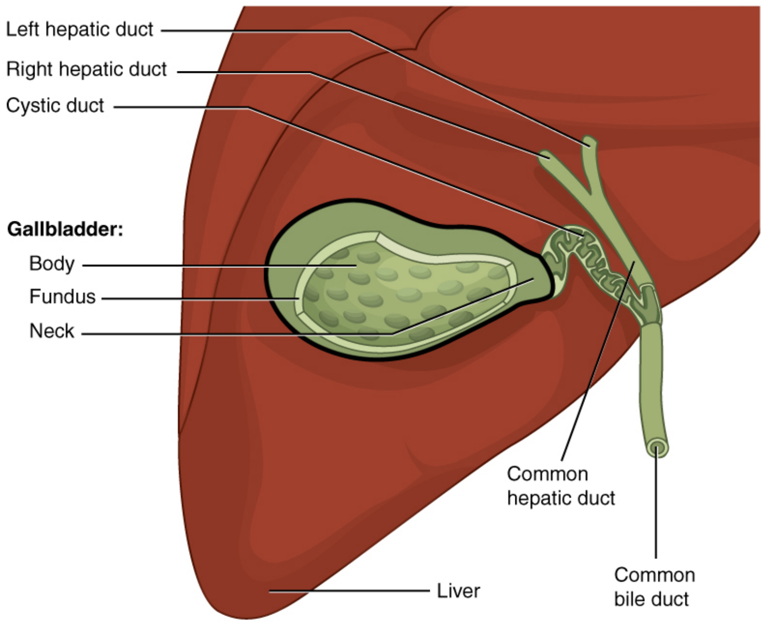
Pancreatic Secretion

Regulation of pancreatic secretion is the job of hormones. The entry of acidic chyme into the duodenum stimulates the release of the hormone **secretin**, which in turn causes the duct cells to release bicarbonate-rich pancreatic juice. The presence of proteins and fats in the duodenum stimulates the secretion of the hormone **CCK**, which then stimulates the acini to secrete enzyme-rich pancreatic juice and enhances the activity of secretin.

The Gallbladder

The **gallbladder** is 3–4 inches long and is nested in a shallow area on the posterior aspect of the right lobe of the liver. This muscular sac stores, concentrates, and, when stimulated, propels the bile into the duodenum via the common bile duct. The **cystic duct** is 1–2 cm (less than 1 in) long and merges with the hepatic duct coming from the liver. The gallbladder's mucosa absorbs water and ions from bile, concentrating it by up to 10-fold and storing the bile until it is needed.

Gallbladder



The gallbladder stores and concentrates bile, and releases it into the two-way cystic duct when it is needed by the small intestine.

Chapter Review

Chemical digestion in the small intestine cannot occur without the help of the liver and pancreas. The liver produces bile and delivers it to the common hepatic duct. Bile contains bile salts and phospholipids, which

emulsify large lipid globules into tiny lipid droplets, a necessary step in lipid digestion and absorption. The gallbladder stores and concentrates bile, releasing it when it is needed by the small intestine.

The pancreas produces the enzyme- and bicarbonate-rich pancreatic juice and delivers it to the small intestine through ducts. Pancreatic juice buffers the acidic gastric juice in chyme, inactivates pepsin from the stomach, and enables the optimal functioning of digestive enzymes in the small intestine.

Glossary

accessory duct
: (also, duct of Santorini) duct that runs from the pancreas into the duodenum

acinus
: cluster of glandular epithelial cells in the pancreas that secretes pancreatic juice in the pancreas

bile
: alkaline solution produced by the liver and important for the emulsification of lipids

bile canaliculus
: small duct between hepatocytes that collects bile

bilirubin
: main bile pigment, which is responsible for the brown color of feces

central vein
: vein that receives blood from hepatic sinusoids

common bile duct
: structure formed by the union of the common hepatic duct and the gallbladder’s cystic duct

common hepatic duct
: duct formed by the merger of the two hepatic ducts

cystic duct
duct through which bile drains and enters the gallbladder

enterohepatic circulation
recycling mechanism that conserves bile salts

enteropeptidase
intestinal brush-border enzyme that activates trypsinogen to trypsin

gallbladder
accessory digestive organ that stores and concentrates bile

hepatic artery
artery that supplies oxygenated blood to the liver

hepatic lobule
hexagonal-shaped structure composed of hepatocytes that radiate outward from a central vein

hepatic portal vein
vein that supplies deoxygenated nutrient-rich blood to the liver

hepatic sinusoid
blood capillaries between rows of hepatocytes that receive blood from the hepatic portal vein and the branches of the hepatic artery

hepatic vein
vein that drains into the inferior vena cava

hepatocytes
major functional cells of the liver

liver
largest gland in the body whose main digestive function is the production of bile

pancreas
accessory digestive organ that secretes pancreatic juice

pancreatic juice

secretion of the pancreas containing digestive enzymes and bicarbonate

porta hepatis

“gateway to the liver” where the hepatic artery and hepatic portal vein enter the liver

portal triad

bile duct, hepatic artery branch, and hepatic portal vein branch

reticuloendothelial cell

(also, Kupffer cell) phagocyte in hepatic sinusoids that filters out material from venous blood from the alimentary canal

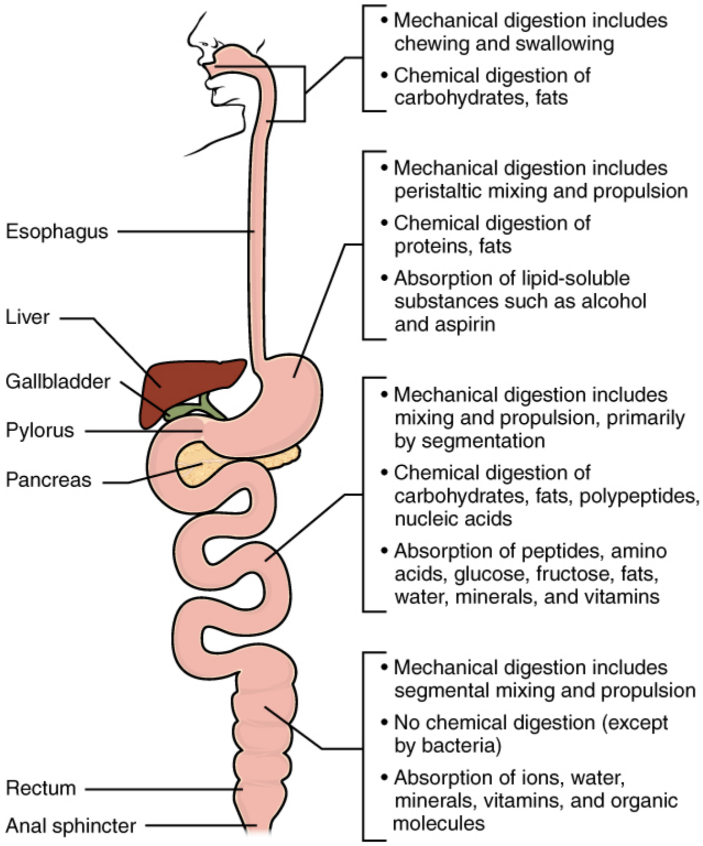
Digestive System Module 7: Chemical Digestion and Absorption: A Closer Look

By the end of this section, you will be able to:

- Identify the locations and primary secretions involved in the chemical digestion of carbohydrates, proteins, lipids, and nucleic acids
- Compare and contrast absorption of the hydrophilic and hydrophobic nutrients

As you have learned, the process of **mechanical digestion** is relatively simple. It involves the physical breakdown of food but does not alter its chemical makeup. **Chemical digestion**, on the other hand, is a complex process that reduces food into its chemical building blocks, which are then absorbed to nourish the cells of the body ([link]). In this section, you will look more closely at the processes of chemical digestion and absorption.

Digestion and Absorption



Digestion begins in the mouth and

continues as food travels through the small intestine. Most absorption occurs in the small intestine.

Chemical Digestion

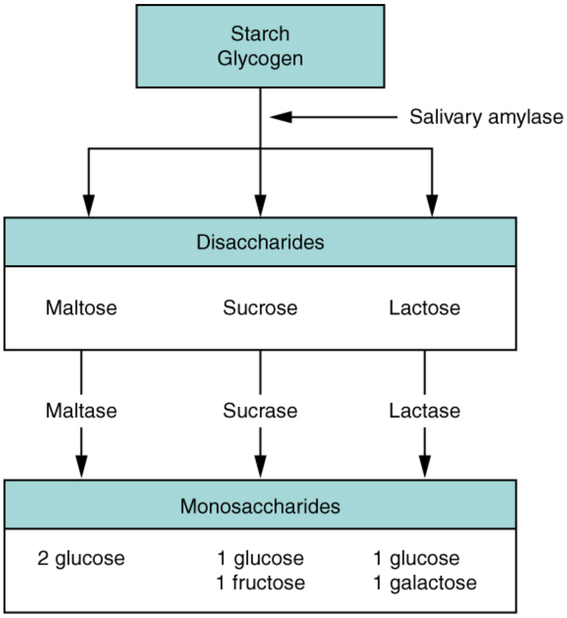
Large food molecules (for example, proteins, lipids, nucleic acids, and starches) must be broken down into subunits that are small enough to be absorbed by the lining of the alimentary canal. This is accomplished by enzymes.

Carbohydrate Digestion

The average American diet is about 50 percent carbohydrates, which may be classified according to the number of monomers (subunits) they contain. **You should take notes on figure 2 below**.

The chemical digestion of starches begins in the mouth and has been reviewed in previous modules. In the small intestine, **pancreatic amylase** does the ‘heavy lifting’ for starch and carbohydrate digestion ([link]). Amylases break down starches into simple sugars. Three brush border enzymes break up the sugars **sucrose, lactose, and maltose** into monosaccharides.

Carbohydrate Digestion Flow Chart



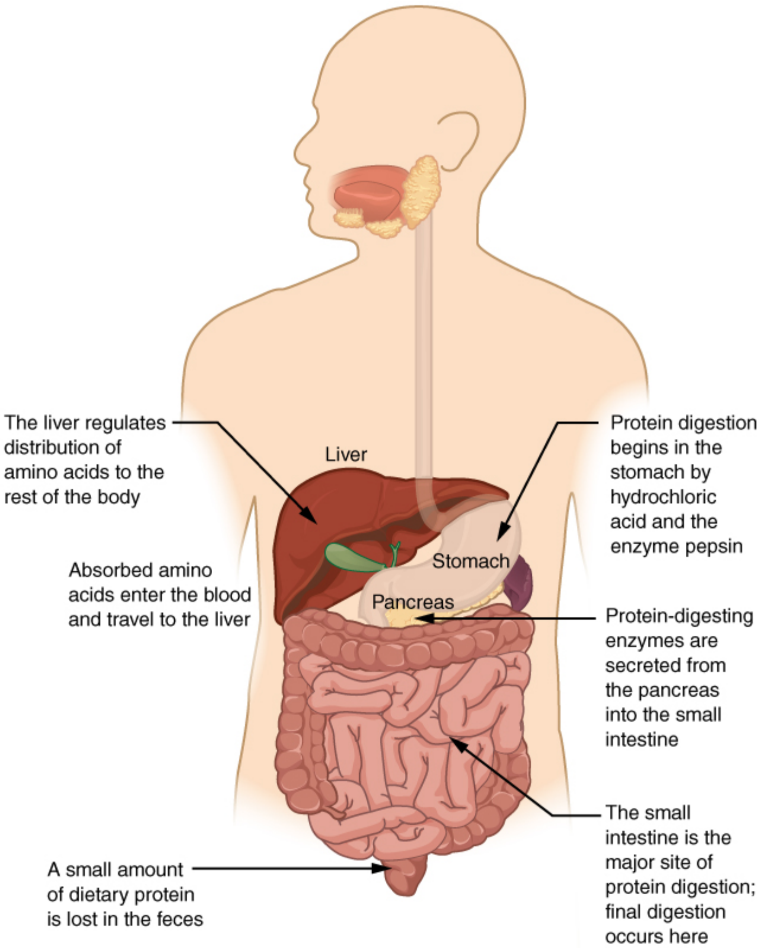
Carbohydrates are broken down into their monomers in a series of steps.

Protein Digestion

Proteins are polymers composed of **amino acids** linked by peptide bonds to form long chains. Digestion reduces them to their constituent amino acids. You usually consume about 15 to 20 percent of your total calorie intake as protein.

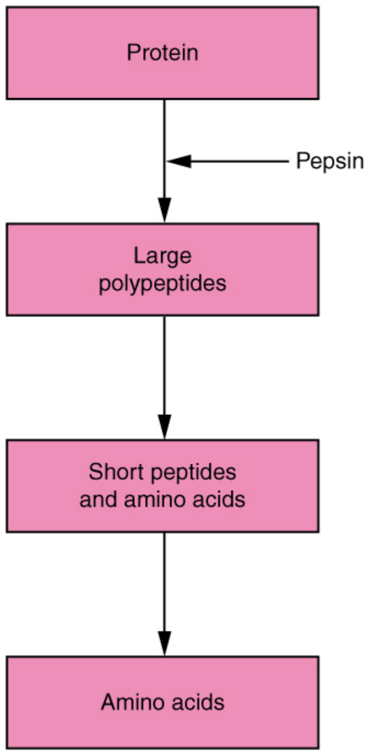
The digestion of protein starts in the stomach, where **HCl** and **pepsin** break proteins into smaller subunits, which then travel to the small intestine ([link]). Chemical digestion in the small intestine is continued by pancreatic enzymes, including **chymotrypsin** and **trypsin**, each of which act on specific bonds in amino acid sequences. At the same time, the cells of the brush border secrete enzymes. This results in molecules small enough to enter the bloodstream ([link]). **Take notes on figure 4**.

Digestion of Protein



The digestion of protein begins in the stomach and is completed in the small intestine.

Digestion of Protein Flow Chart



Proteins are successively broken down into their amino acid components.

Lipid Digestion

A healthy diet limits lipid intake to 35 percent of total calorie intake. The most common dietary lipids are triglycerides, which are made up of a glycerol molecule bound to three fatty acid chains. Small amounts of dietary cholesterol and phospholipids are also consumed.

The lipase primarily responsible for lipid digestion is **pancreatic lipase**. However, because the pancreas is the only consequential source of lipase, virtually all lipid digestion occurs in the small intestine. Pancreatic lipase

breaks down each triglyceride into subunits called **free fatty acids and monoglycerides**.

Nucleic Acid Digestion

The nucleic acids DNA and RNA are found in most of the foods you eat. Two types of **pancreatic nuclease** are responsible for their digestion. The nucleotides produced by this digestion are further broken down by two intestinal brush border enzymes so they be through the alimentary canal wall. The large food molecules that must be broken down into subunits are summarized [link]

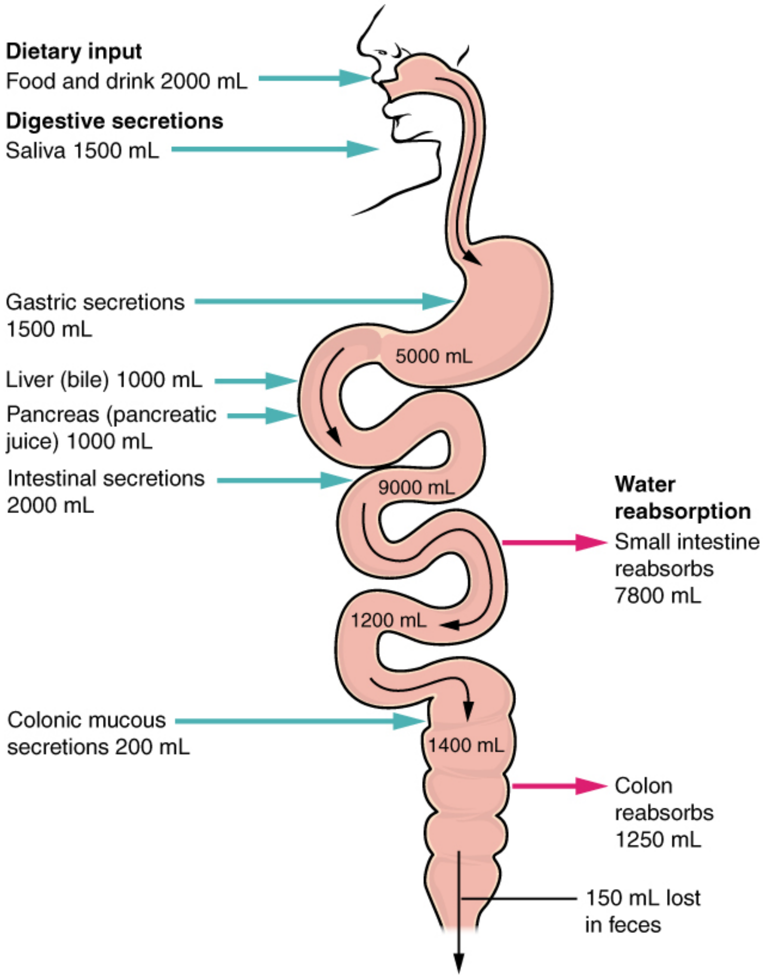
Absorbable Food Substances	
Source	**Substance**
Carbohydrates	Monosaccharides: glucose, galactose, and fructose
Proteins	Single amino acids, dipeptides, and tripeptides
Triglycerides	Monoacylglycerides, glycerol, and free fatty acids
Nucleic acids	Pentose sugars, phosphates, and nitrogenous bases

Absorption

The mechanical and digestive processes have one goal: to convert food into molecules small enough to be absorbed by the epithelial cells of the intestinal villi. By the time chyme passes from the ileum into the large

intestine, it is essentially indigestible food residue (mainly plant fibers like cellulose), some water, and millions of bacteria ([link]).

Digestive Secretions and Absorption of Water



Absorption is a complex process, in which nutrients from digested food are harvested.

Absorption can occur through several mechanisms: **active transport** to the movement of a substance across a cell membrane using cellular energy (ATP) to move the substance refers to an area of lower concentration to an area of higher concentration using cellular energy (ATP) to move the substance. Passive diffusion refers to the movement of substances from an area of higher concentration to an area of lower concentration.

Carbohydrate Absorption

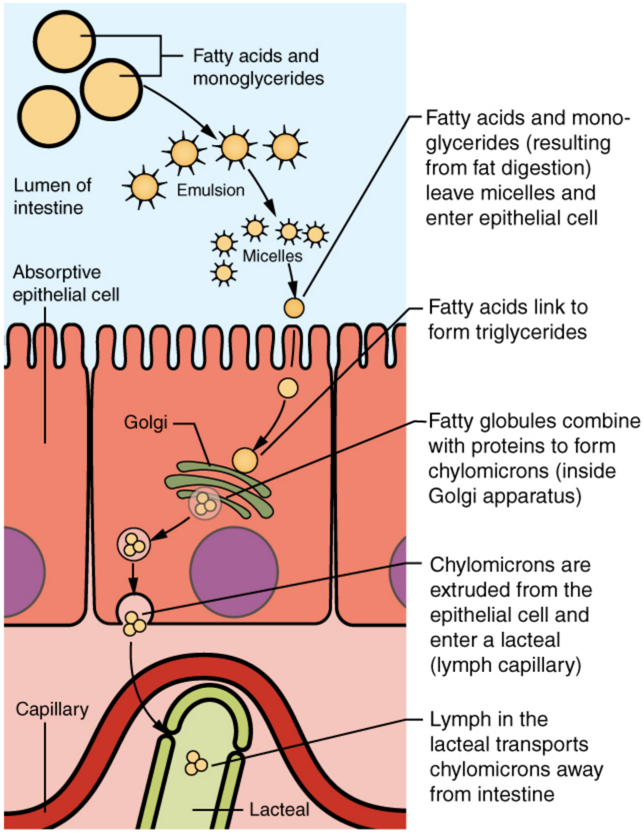
All carbohydrates are absorbed in the form of monosaccharides. The small intestine is highly efficient at this, absorbing monosaccharides at an estimated rate of 120 grams per hour. All normally digested dietary carbohydrates are absorbed; indigestible fibers are eliminated in the feces.

Protein Absorption

Active transport mechanisms, primarily in the duodenum and jejunum, absorb most proteins as their breakdown products, amino acids. Almost all (95 to 98 percent) protein is digested and absorbed in the small intestine via diffusion.

Lipid Absorption

About 95 percent of lipids are absorbed in the small intestine. Bile salts not only speed up lipid digestion, they are also essential to the absorption of the end products of lipid digestion. The lipid subunits are too big to pass through the basement membranes of blood capillaries, instead they enter the large pores of **lacteals**. The lacteals come together to form the lymphatic vessels. the lymphatic vessels and are part of the lymphatic system..
Lipid Absorption



Unlike amino acids and simple sugars, lipids are transformed as they are absorbed through epithelial cells.

Nucleic Acid Absorption

The products of nucleic acid digestion—pentose sugars, nitrogenous bases, and phosphate ions—are transported by carriers across the villus epithelium via active transport. These products then enter the bloodstream.

Water Absorption

Each day, about nine liters of fluid enter the small intestine. About 2.3 liters are ingested in foods and beverages, and the rest is from GI secretions. About 90 percent of this water is absorbed in the small intestine. Water absorption is driven by the concentration gradient of the water: The concentration of water is higher in chyme than it is in epithelial cells. Thus, water moves down its concentration gradient from the chyme into cells. As noted earlier, much of the remaining water is then absorbed in the colon.

Chapter Review

The small intestine is the site of most chemical digestion and almost all absorption. Chemical digestion breaks large food molecules down into their chemical building blocks, which can then be absorbed through the intestinal wall and into the general circulation. Intestinal brush border enzymes and pancreatic enzymes are responsible for the majority of chemical digestion. The breakdown of fat also requires bile.

Most nutrients are absorbed by transport mechanisms at the apical surface of enterocytes. Exceptions include lipids, fat-soluble vitamins, and most water-soluble vitamins. With the help of bile salts and lecithin, the dietary fats are emulsified to form micelles, which can carry the fat particles to the surface of the enterocytes. There, the micelles release their fats to diffuse across the cell membrane. The fats are then reassembled into triglycerides and mixed with other lipids and proteins into chylomicrons that can pass into lacteals. Other absorbed monomers travel from blood capillaries in the villus to the hepatic portal vein and then to the liver.

Glossary

α-dextrin
: breakdown product of starch

α-dextrinase
: brush border enzyme that acts on α-dextrins

aminopeptidase
: brush border enzyme that acts on proteins

chylomicron
: large lipid-transport compound made up of triglycerides, phospholipids, cholesterol, and proteins

deoxyribonuclease
: pancreatic enzyme that digests DNA

dipeptidase
: brush border enzyme that acts on proteins

lactase
: brush border enzyme that breaks down lactose into glucose and galactose

lipoprotein lipase
: enzyme that breaks down triglycerides in chylomicrons into fatty acids and monoglycerides

maltase
: brush border enzyme that breaks down maltose and maltotriose into two and three molecules of glucose, respectively

micelle
: tiny lipid-transport compound composed of bile salts and phospholipids with a fatty acid and monoacylglyceride core

nucleosidase
: brush border enzyme that digests nucleotides

pancreatic amylase
: enzyme secreted by the pancreas that completes the chemical digestion of carbohydrates in the small intestine

pancreatic lipase
: enzyme secreted by the pancreas that participates in lipid digestion

pancreatic nuclease

enzyme secreted by the pancreas that participates in nucleic acid digestion

phosphatase
: brush border enzyme that digests nucleotides

ribonuclease
: pancreatic enzyme that digests RNA

sucrase
: brush border enzyme that breaks down sucrose into glucose and fructose